PATENT ABSTRACTS OF JAPAN

(11)Publication number : 2003-080449
(43)Date of publication of application : 18.03.2003

(51)Int.Cl. B24B 27/06

(21)Application number : 2001-270608
(22)Date of filing : 06.09.2001

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(54) METHOD OF CUTTING RARE EARTH ALLOY AND METHOD OF MAKING RARE EARTH MAGNET

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a method of cutting a rate earth alloy by a fixed abrasive grain wire saw which can execute cutting by using a cooling fluid mainly composed of water.
SOLUTION: In this method of cutting a rare earth alloy, using a wire saw securing abrasive grains to a core wire, the rare earth alloy, placing its part cut by the wire saw in a condition immersed in a cooling fluid mainly composed of water, is cut by making the wire saw run. The cooling fluid is contained with an extreme pressure agent by volumetric reference of 500 ppm or more but 20,000 ppm or less.

LEGAL STATUS

[Date of request for examination]

[Date of sending the examiner's decision of rejection]

[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's decision of rejection]

[Date of requesting appeal against examiner's decision of rejection]

[Date of extinction of right]

SR3131(6)

(19)日本国特許庁（ＪＰ）　(12) 公開特許公報（Ａ）　(11)特許出願公開番号

特開2003－80449

（P2003－80449A）

(43)公開日　平成15年３月18日(2003.3.18)

(51)Int.Cl.⁷	識別記号	ＦＩ	テーマコード゛(参考)
Ｂ２４Ｂ　27/06		Ｂ２４Ｂ　27/06	Ｄ　３Ｃ０５８
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審査請求　未請求　請求項の数20　ＯＬ　（全 11 頁）

(21)出願番号　特願2001－270608(P2001－270608)

(22)出願日　平成13年９月６日(2001.9.6)

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(54)【発明の名称】　希土類合金の切断方法および希土類磁石の製造方法

(57)【要約】

【課題】　水を主成分とする冷却液を用いて実行できる、固定砥粒ワイヤソーによる希土類合金の切断方法を提供する。

【解決手段】　芯線に砥粒を固着させたワイヤソーを用いる希土類合金の切断方法であって、希土類合金がワイヤソーによって切削される部分を水を主成分とする冷却液に浸漬した状態で、ワイヤソーを走行させることによって希土類合金を切削する。冷却液は体積基準で５００ｐｐｍ以上２００００ｐｐｍ以下の極圧添加剤を含有する。

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【特許請求の範囲】
【請求項１】　芯線に砥粒を固着させたワイヤソーを用いる希土類合金の切断方法であって、
前記希土類合金が前記ワイヤソーによって切削される部分を水を主成分とする冷却液に浸漬した状態で、前記ワイヤソーを走行させせることによって前記希土類合金を切削する工程を包含し、前記冷却液が体積基準で５００ｐｐｍ以上２００００ｐｐｍ以下の極圧添加剤を含有する、希土類合金の切断方法。
【請求項２】　前記極圧添加剤は硫黄含有化合物である、請求項１に記載の希土類合金の切断方法。
【請求項３】　前記冷却液の２５°Ｃにおける表面張力は２５ｍＮ／ｍ～６０ｍＮ／ｍの範囲内にある、請求項１または２に記載の希土類合金の切断方法。
【請求項４】　前記冷却液は、水溶性の合成潤滑剤と、前記合成潤滑剤の重量の１０倍～５０倍の範囲内の重量の水を含んでいる、請求項１から３のいずれかに記載の希土類合金の切断方法。
【請求項５】　前記冷却液は、界面活性剤と、界面活性剤の重量の１０倍～５０倍の範囲内の重量の水を含んでいる、請求項１から３のいずれかに記載の希土類合金の切断方法。
【請求項６】　前記冷却液は、消泡剤を含んでいる請求項１から５のいずれかに記載の希土類合金の切断方法。
【請求項７】　前記冷却液は、ＰＨが８～１１である請求項１から６のいずれかに記載の希土類合金の切断方法。
【請求項８】　前記冷却液は、防錆剤を含んでいる請求項１から７のいずれかに記載の希土類合金の切断方法。
【請求項９】　前記砥粒は、前記芯線の外周面に形成されたフェノール樹脂層によって固着されている、請求項１から８のいずれかに記載の希土類合金の切断方法。
【請求項１０】　前記ワイヤソーの走行方向における、互いに隣接する前記砥粒間の平均距離は、前記砥粒の平均粒径の２００％～６００％の範囲内にあり、且つ、前記砥粒が前記フェノール樹脂層の表面から突出している部分の平均高さは、１０μｍ～４０μｍの範囲内にある、請求項１から９のいずれかに記載の希土類合金の切断方法。
【請求項１１】　前記砥粒の平均粒径Ｄは、２０μｍ≦Ｄ≦６０μｍの関係を満足する、請求項１から１０のいずれかに記載の希土類合金の切断方法。
【請求項１２】　前記切削工程において、前記希土類合金が前記ワイヤソーによって切削される部分が槽内に収容された前記冷却液に浸漬され、前記冷却液は、前記槽の底部から前記槽内に供給されるとともに、前記槽の開口部から供給されることによって、前記開口部から溢れ出る状態に維持される、請求項１から１１のいずれかに記載の希土類合金の切断方法。
【請求項１３】　前記切削工程において、前記冷却液が

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１分間に溢れ出る量は、前記槽の容積の５０％以上である、請求項１２に記載の希土類合金の切断方法。
【請求項１４】　前記切削工程において、前記開口部から供給される前記冷却液の量は、前記底部から供給される前記冷却液の量よりも多い、請求項１０または１３に記載の希土類合金の切断方法。
【請求項１５】　前記切削工程において、前記槽の前記開口部に、カーテン状の気流または冷却液流を形成することによって、前記冷却液が前記槽の前記開口部から溢れ出るのを抑制する、請求項１２から１４のいずれかに記載の希土類合金の切断方法。
【請求項１６】　前記希土類合金は、Ｒ－Ｆｅ－Ｂ系希土類焼結合金である請求項１から１５のいずれかに記載の希土類合金の切断方法。
【請求項１７】　前記希土類合金は、Ｎｄ－Ｆｅ－Ｂ系希土類焼結合金である請求項１６に記載の希土類合金の切断方法。
【請求項１８】　希土類合金粉末から希土類磁石の焼結体を作製する工程と、
請求項１から１７のいずれかに記載の希土類合金の切断方法を用いて前記焼結体から複数の希土類磁石を分離する工程と、
を包含する希土類磁石の製造方法。
【請求項１９】　請求項１８に記載の希土類磁石の製造方法によって作製された希土類磁石を備えているボイスコイルモータ。
【請求項２０】　前記希土類磁石の厚さが０．５ｍｍ～３．０ｍｍの範囲にある請求項１９に記載のボイスコイルモータ。
【発明の詳細な説明】
【０００１】
【発明の属する技術分野】本発明は、希土類合金の切断方法および希土類磁石の製造方法に関し、特に、芯線に砥粒を固着させたワイヤソーを用いて希土類合金を切断する方法およびそれを用いた希土類磁石の製造方法に関する。
【０００２】
【従来の技術】希土類合金は、例えば、強力な磁石の材料として利用されている。希土類合金を着磁することによって得られる希土類磁石は、例えば、磁気記録装置の磁気ヘッドの位置決めに用いられるボイスコイルモータ用の磁石として好適に用いられている。
【０００３】希土類合金のインゴット（焼結体を含むものとする。）を切断する方法としては、従来から、例えば回転するスライシングブレードを用いてインゴットをスライスする技術が採用されている。しかしながら、スライシングブレードで切断する方法によれば、切断刃の厚さは比較的大きいため、削り代が多くなり、希土類合金材料の歩留まりが低く、希土類合金製品（例えば希土類磁石）のコストを上昇させる要因となっている。

【０００４】スライシングブレードよりも削りしろが少ない切断方法として、ワイヤソーを用いた方法がある。例えば、特開平１１－１９８０２０号公報は、高強度の芯線の周面上に超砥粒をボンド層により固定したワイヤソー（「固定砥粒ワイヤー」という。）を用いて、シリコン、ガラス、ネオジム、フェライト等の硬脆材料を切断できることを開示している。

【０００５】

【発明が解決しようとする課題】上述のような固定砥粒ワイヤソーを用いて、希土類合金のインゴットから少ない削り代で所定厚さの板を多数枚同時に作製することができれば、希土類磁石の製造コストが大幅に低減される。しかしながら、固定砥粒ワイヤソーを用いて希土類合金を量産レベルで切断したとの報告は未だに無い。

【０００６】発明者が種々検討した結果から、この主な原因として、希土類合金、特に、焼結法によって製造された希土類合金（以下、「希土類焼結合金」を呼ぶ。）の機械的な性質が、シリコン等と大きく異なることが挙げられる。具体的には、希土類焼結合金は、主に脆性的な破壊を起こす硬い主相（$R_2Fe_{14}B$相）と、延性的な破壊を起こす粒界相（Ｒリッチ相）とを有するので、シリコンに代表される硬脆材料と異なり、切削され難い。すなわち、シリコン等の硬脆材料を切断する場合に比べて、切削抵抗が高く、その結果、発熱量も多い。また、希土類合金の比重は、約７．５とシリコン等の材料に比べて大きく、切削によって生成される切削屑（スラッジ）が切削部から排出され難い。

【０００７】従って、希土類合金を、高い加工精度で、効率良く切削するためには、切削抵抗を十分に低下させるとともに、切削時に発生する熱を効率良く放熱する、すなわち切削部を効率良く冷却する必要がある。また、切削によって生成される切削屑を効率良く排出する必要がある。

【０００８】潤滑性に優れた冷却液（「切削液」ともいう。）を希土類合金の切削部に十分に供給することによって、切削抵抗を低下するとともに、切削時に発生する熱を効率良く放散することができる。発明者による実験の結果、油性の冷却液を用いて、ワイヤソーを十分な量の冷却液で濡らしておけば、走行するワイヤソーによって、狭い切削部に冷却液を十分に供給することができる。

【０００９】しかしながら、油性の冷却液には、環境破壊を起こさないように廃液を処理するためにコストがかかること、および、廃液中の切削屑を分別することが困難であり、廃液や切削屑の再利用が困難であるという問題がある。また、切削屑を再利用する際に、原料中の炭素含有量が増加し、磁気特性を低下させるため好ましくないという問題もある。これらのことを考慮すると、冷却液としては水（または水溶性の冷却液）が好ましいのであるが、水を冷却液として用いると、水は粘度（１．０mm^2／ｓ）が低いので、走行するワイヤソーに十分な量を付着させることができないので、ワイヤソーを水で濡らしても切削部に十分な量の水を供給することができない。

【００１０】特開平１１－１９８０２０号公報は、冷却液の槽からオーバーフローする冷却液中にワイヤソーを走行させることによって、固定砥粒ワイヤソーを高速（例えば２０００ｍ／ｍｉｎ）で走行させる場合においても、冷却液をワイヤソーに確実に付着させることができることを開示している。しかしながら、本発明者の実験によると、オーバーフローしている水の中にワイヤソー（例えば、特開平１１－１９８０２０号公報に開示されている）を走行させながら希土類合金を切削しても、砥粒の脱落や、ひどい場合にはワイヤソーの断線が発生する。この不具合は、ワイヤソーの走行速度が例えば８００ｍ／ｍｉｎ程度でも発生した。これは、上記の方法を採用しても、切削抵抗が高く、また、水が切削部に十分に供給されないためと考えられる。

【００１１】本発明は斯かる諸点に鑑みてなされたものであり、その主な目的は、水を主成分とする冷却液を用いて実行できる、固定砥粒ワイヤソーによる希土類合金の切断方法を提供することにある。また、本発明の他の目的は、上記希土類合金の切断方法を用いた希土類磁石の製造方法、ならびに当該希土類磁石を備えたボイスコイルモータを提供することにある。

【００１２】

【課題を解決するための手段】本発明による希土類合金の切断方法は、芯線に砥粒を固着させたワイヤソーを用いる希土類合金の切断方法であって、前記希土類合金が前記ワイヤソーによって切削される部分を水を主成分とする冷却液に浸漬した状態で、前記ワイヤソーを走行させることによって前記希土類合金を切削する工程を包含し、前記冷却液が体積基準で５００ｐｐｍ以上２００００ｐｐｍ以下の極圧添加剤を含有することを特徴とし、そのことによって上記目的が達成される。

【００１３】前記極圧添加剤は硫黄含有化合物であることが好ましい。

【００１４】前記冷却液の２５°Ｃにおける表面張力は２５ｍＮ／ｍ～６０ｍＮ／ｍの範囲内にあることが好ましい。

【００１５】前記冷却液は、水溶性の合成潤滑剤と、前記合成潤滑剤の重量の１０倍～５０倍の範囲内の重量の水を含んでいることが好ましい。

【００１６】あるいは、前記冷却液は、界面活性剤と、界面活性剤の重量の１０倍～５０倍の範囲内の重量の水を含んでもよい。

【００１７】前記冷却液は消泡剤を含んでもよい。前記冷却液は、ＰＨが８～１１であることが好ましい。また、前記冷却液は、防錆剤を含んでもよい。

【００１８】前記砥粒は、前記芯線の外周面に形成され

たフェノール樹脂層によって固着されていることが好ましい。

【００１９】前記ワイヤソーの走行方向における、互いに隣接する前記砥粒間の平均距離は、前記砥粒の平均粒径の２００％～６００％の範囲内にあり、且つ、前記砥粒が前記フェノール樹脂層の表面から突出している部分の平均高さは、１０μm～４０μmの範囲内にあることが好ましい。

【００２０】前記砥粒の平均粒径Ｄは、２０μｍ≦Ｄ≦６０μｍの関係を満足することが好ましい。

【００２１】前記切削工程において、前記希土類合金が前記ワイヤソーによって切削される部分が槽内に収容された前記冷却液に浸漬され、前記冷却液は、前記槽の底部から前記槽内に供給されるとともに、前記槽の開口部から供給されることによって、前記開口部から溢れ出る状態に維持されることが好ましい。

【００２２】前記切削工程において、前記冷却液が１分間に溢れ出る量は、前記槽の容積の５０％以上であることが好ましい。

【００２３】前記切削工程において、前記開口部から供給される前記冷却液の量は、前記底部から供給される前記冷却液の量よりも多いことが好ましい。

【００２４】前記切削工程において、前記槽の前記開口部に、カーテン状の気流または冷却液流を形成することによって、前記冷却液が前記槽の前記開口部から溢れ出るのを抑制することが好ましい。

【００２５】前記希土類合金は、Ｒ－Ｆｅ－Ｂ系希土類焼結合金であってよく、Ｎｄ－Ｆｅ－Ｂ系希土類焼結合金であってもよい。なお、ＲはＹを含む希土類元素である。

【００２６】本発明の希土類磁石の製造方法は、希土類合金粉末から希土類磁石の焼結体を作製する工程と、上記のいずれかの希土類合金の切断方法を用いて前記焼結体から複数の希土類磁石を分離する工程とを包含し、そのことによって上記目的が達成される。

【００２７】本発明によるボイスコイルモータは、上記の希土類磁石の製造方法によって作製された希土類磁石を備えている。前記希土類磁石の厚さが０．５mm～３．０mmの範囲にあってもよい。

【００２８】

【発明の実施の形態】以下に、本発明による実施形態の希土類合金の切断方法および希土類磁石の製造方法を説明する。

【００２９】本発明による希土類合金の切断方法は、芯線（典型的にはピアノ線）に砥粒（典型的にはダイヤモンド砥粒）を固着させたワイヤソーを用いる希土類合金の切断方法であって、希土類合金がワイヤソーによって切削される部分に水を主成分とする冷却液を供給しながら、ワイヤソーを走行させることによって希土類合金を切削する工程を包含し、冷却液が体積基準で５００ｐｐｍ以上２００００ｐｐｍ以下の極圧添加剤を含有する。極圧添加剤は硫黄含有化合物であることが好ましい。なお、本明細書において、「水を主成分とする冷却液」とは、全体の７０重量％以上が水である冷却液をいう。

【００３０】極圧添加剤は、切断時に発生する摩擦熱によって、希土類合金を構成する金属元素（主に鉄）と化学的に反応して金属化合物を形成する。そのため、希土類合金は切削し難いが、その延性が極圧添加剤によって低減され、切削抵抗が低くなる。従って、油性の冷却液に比べ潤滑性が低い水系の冷却液を用いても、希土類合金を効率よく切断することが可能になる。

【００３１】極圧添加剤としては、硫黄（Ｓ）を含有する化合物（硫黄系極圧添加剤と呼ばれることもある）を用いることが好ましい。硫黄系極圧添加剤は、希土類合金に含まれる鉄と反応し鉄硫化物を形成し、接触面を脆化させる効果に優れている。なお、硫黄系極圧添加物のほかに、例えば、燐系極圧添加剤や、燐－硫黄系極圧添加剤を用いることもできる。

【００３２】本発明の冷却液に添加される極圧添加剤として好適に用いられる硫黄含有化合物は、特に限定されないが、水に対する親和性（溶解性または均一分散性）が高いものが好ましく、酸または塩あるいは低級アルコールであることが好ましい。例えば、硫化脂肪酸、メルカプト脂肪酸、チオカルボン酸、ポリスルフィドのα、ωジカルボン酸などの有機酸およびこれらの塩やメルカプトアルコールなどを挙げることができる。特に、硫化脂肪酸およびポリスルフィドのα、ωジカルボン酸やこれらの塩が好ましい。硫黄含有化合物は１種を単独で用いても良いし、２種以上を組み合わせて用いても良い。

【００３３】極圧添加剤の冷却液全体に対する添加量は、体積基準で５００ｐｐｍ以上２００００ｐｐｍ以下であることが好ましく、１０００ｐｐｍ以上５０００ｐｐｍ以下であることがさらに好ましい。５００ｐｐｍ未満であると極圧添加剤の効果が十分に発揮されないことがあり、２００００ｐｐｍを超えると、希土類合金と必要以上に反応し、信頼性（耐食性）を損ねることがある。

【００３４】さらに、冷却液の２５°Ｃにおける表面張力は２５ｍＮ／ｍ～６０ｍＮ／ｍの範囲内にあることが好ましい。冷却液として、希土類合金に対する２５°Ｃにおける動摩擦係数が０．１～０．３のものを用いてもよい。

【００３５】希土類合金を固定砥粒ワイヤソーを用いて切削する工程を、２５°Ｃにおける表面張力が約２５ｍＮ／ｍ～約６０ｍＮ／ｍ（約２５ｄｙｎ／ｃｍ～約６０ｄｙｎ／ｃｍ）の範囲内にある冷却液に切削部が浸漬された状態で実行することによって、ワイヤソーを効率良く冷却することができる。上記の範囲内の表面張力を有する冷却液は、水に比べて、希土類合金および／またはワイヤソーに対する濡れ性（またはなじみ）が優れるの

で、切削部（希土類合金とワイヤソーとが互いに接触し、希土類合金が切削される部分。切削溝ともいう。）に冷却液が効率よく浸透するためと考えられる。勿論、水を主成分とする冷却液は、油性冷却液（例えば鉱油）に比べ比熱が大きいので、冷却効率が高い。

【００３６】本発明の希土類合金の切断方法において好適に用いられる冷却液は、上記希土類合金に対する動摩擦係数によって選別することも可能で、２５°Ｃにおける上記動摩擦係数が約０．１～約０．３の範囲内にある冷却液は、上記の範囲内の表面張力を有する冷却液と同等の作用・効果を発揮し得る。表面張力が切削部に対する冷却液の浸透性を示す指標と考えられるのに対し、動摩擦係数は切削部に対して冷却液が与える潤滑性の指標と考えられる。なお、表面張力と動摩擦係数との間に、定性的な相関関係があることが知られている。

【００３７】冷却液の表面張力は、よく知られているデュヌイ表面張力計を用いて測定される。また、希土類合金に対する冷却液の動的摩擦係数は、日本で基礎的な試験機として多用されている増田式「四球式摩擦試験機」を用いて測定される。本明細書においては、いずれも、２５°Ｃにおける値を、冷却液を特徴付ける値として採用する。

【００３８】なお、以下の実施例で示す動摩擦係数は、鉄球を用いて四球式摩擦試験機で求めた値である。実施例で例示するＲ－Ｆｅ－Ｂ系希土類合金（例えば、$Nd_2Fe_{14}B$金属間化合物を主相とする合金）は、鉄の含有量が成分元素の中で最も多いので、鉄球を用いて求めた冷却液の動摩擦係数は、良い近似で、希土類合金に対する動摩擦係数として採用することができる。希土類磁石として好適に用いられる希土類合金の組成および製造方法は、例えば、米国特許第４，７７０，７２３号および米国特許第４，７９２，３６８号に記載されている。

【００３９】なお、２５°Ｃの表面張力または動摩擦係数を用いて、本発明の切断方法で好適に用いられる冷却液を特定したが、実際に使用する際の冷却液の温度は、２５°Ｃに限られない。但し、本発明の効果を得るためには、１５°Ｃ～３５°Ｃの範囲内に温度制御された冷却液を用いることが好ましく、２０°Ｃ～３０°Ｃの範囲内にあることがさらに好ましく、２０°Ｃ～２５°Ｃの範囲内にあることがさらに好ましい。よく知られているように、冷却液の表面張力や動摩擦係数は温度に依存するので、実際に使用する冷却液の温度が上記の温度範囲からあまり外れると、冷却液の表面張力や動摩擦係数がそれぞれ上記の数値範囲から外れた状態と良く似た状態となり、冷却効率が低下する。

【００４０】上記範囲の表面張力（または動摩擦係数）を有する冷却液を用いることによって、ワイヤソーの温度の異常上昇を抑制することができるので、砥粒の異常脱粒やワイヤソーの断線をさらに効率よく抑制・防止することができる。その結果、加工精度の低下が防止されるとともに、従来よりも長い期間に亘ってワイヤソーを使用することが可能となるので製造コストを低減することができる。

【００４１】上記範囲の表面張力（または動摩擦係数）を有する冷却液は、界面活性剤や、いわゆる「シンセティック（Ｓｙｎｔｈｅｔｉｃ）」と呼ばれる合成潤滑剤を水に添加することによって調製される。種類や添加量を調整することによって、所定の表面張力や動摩擦係数を得ることができる。また、水を主成分とする冷却液を用いると、比較的粘度が低いので、切削によって生成したスラッジから磁石を用いて希土類合金の切削屑を容易に分別することが可能で、冷却液を再利用することができる。また、冷却液の廃棄処理によって自然環境に悪影響を及ぼすことを防止することができる。また、スラッジ中に含まれる炭素の量を減らすことができ、スラッジから回収された切削屑を原料とする磁石の磁気特性を向上することができる。

【００４２】ワイヤソーを高速で走行させながら切削を行うと、冷却液が発泡し、冷却効率が低下することがある。消泡剤を含む冷却液を用いることによって、冷却液の発泡による冷却効率の低下を抑制することができる。さらに、ＰＨが８～１１の範囲内にある冷却液を用いることによって、希土類合金の腐食を抑制することができる。また、防錆剤を含む冷却液を用いることによって、希土類合金の酸化を抑制することができる。これらは、希土類合金の種類や切断条件等を考慮して、適宜調整すればよい。

【００４３】ワイヤソーとしては、ダイヤモンド系砥粒を樹脂で固着したものが好適に用いられる。すなわち、芯線（典型的にはピアノ線）の外周面にダイヤモンド系砥粒を樹脂を用いて固着したワイヤソーを好適に用いることができる。そのなかでも、樹脂としてフェノール樹脂を用いることが好ましい。フェノール樹脂は、ピアノ線（硬鋼線）の外周面への接着強度が高く、また後述する冷却液に対する濡れ性（浸透性）にも優れる。また、電着法を用いて製造されるワイヤソーよりも安価であり、希土類合金の切断にかかるコストを低減することができる。電着法（例えば、Ｎｉめっき等によって砥粒を固定）によって作製されたワイヤソーに比べると砥粒の固着力は弱いが、動摩擦係数を上述した範囲に調整された冷却液を用いることによって砥粒のはがれ等を少なくできるため、切削し難い希土類合金を切断することが可能となる。

【００４４】なお、ワイヤソーの芯線は、ピアノ線に限られず、Ｎｉ－ＣｒやＦｅ－Ｎｉ等の合金、ＷやＭｏ等の高融点金属から形成されたもの、またはナイロン繊維などの高強度繊維を束ねたものから形成されていても良い。また、砥粒の材料はダイヤモンドに限定されず、ＳｉＣ、Ｂ、Ｃ、ＣＢＮ(Cubic Boron Nitride)等であってもよい。

【００４５】切削しろが少ないという利点を得るためには、ワイヤソーの外径は、０．３mm以下が好ましく、０．２５mm以下であることがさらに好ましい。ワイヤソーの外径の下限値は、十分な強度が得られるように設定され、且つ、所定の大きさの砥粒を十分な強度で固着するために、０．１２～０．２０mm程度の直径の芯線が用いられる。砥粒の平均粒径Ｄは、切削効率の観点から、２０μm≦Ｄ≦６０μmの関係を満足することが好ましく、特に、４０μm≦Ｄ≦６０μmの関係を満足することが好ましい。また、切削効率と切削屑（スラッジ）の排出効率の観点から、ワイヤソーの走行方向における、互いに隣接する砥粒間の平均距離は、砥粒の平均粒径Ｄの２００％～６００％の範囲内にあることが好ましく、且つ、砥粒がフェノール樹脂層の表面から突出している部分の平均高さは、１０μm～４０μmの範囲内にあることが好ましい。このワイヤソーは、上記の仕様を指定すれば一般のワイヤソーの製造業者（例えば、株式会社アライドマテリアル）から供給され得る。

【００４６】このようなワイヤソーを用いると、良好な切削効率が実現でき、且つ、切削屑の排出性にも優れるので、比較的高い走行速度（例えば１０００m／min）でも切削できる。また、上記の冷却液によって効率良く冷却されるので、良好な加工精度で、長期間に亘って安定に希土類合金を切削することができる。

【００４７】本発明の切断方法に用いる水を主成分とする冷却液は、粘度が低い（動粘度が約１mm^2／s）ので、切削屑の排出性が油性の冷却液（一般に動粘度は５mm^2／s以上）よりも低い。そこで、切削屑の排出性を高めるために、切削工程において、切削部が槽内に収容された冷却液に浸漬された状態に維持され、且つ、冷却液は、槽の底部から槽内に供給されるとともに、槽の開口部から供給されることによって、槽の開口部から溢れ出る状態に維持されることが好ましい。

【００４８】粘度の低い冷却液中に排出された切削屑は、容易に沈降し、槽の開口部付近に浮遊する切削屑は僅かである。切削部を冷却液中に浸漬した状態で切削するためには、ワイヤソーは槽の開口部付近の冷却液中を走行するように配置されるので、ワイヤソーは切削屑の少ない冷却液中を走行し、切削部には切削屑の少ない冷却液が供給される。特に、槽の開口部からも冷却液を供給し、開口部から溢れる状態に維持することによって、切削部に供給される冷却液中の切削屑の量を低下させることができる。さらに、槽の開口部から供給される冷却液の流れによって、ワイヤソーに付着した切削屑を機械的に洗い流す効果も得られる。冷却液が１分間に溢れ出る量は、槽の容積の５０％以上であることが好ましい。また、開口部から供給される冷却液の量は、槽の底部から供給される冷却液の量よりも多いことが好ましい。

【００４９】さらに、槽の開口部にカーテン状の冷却液流（または気流）を形成し、冷却液が槽の開口部から溢れ出るのを抑制することによって、溢れ出る冷却液の液面を槽の壁よりも高くすると、より多くの冷却液が切削部の周囲に供給されることになるので、冷却液中の切削屑の量をさらに低下させることができる。ここでは、ワイヤソーの走行方向と交差する槽の開口部の辺上にカーテン状に冷却液流を形成した。冷却液流を形成するための吐出圧は、２０MPa（２kgf）～１００MPa（１０kgf）の範囲内にあることが好ましく、４０MPa（４kgf）～６０MPa（６kgf）の範囲内にあることがさらに好ましい。この範囲よりも吐出圧が低いと充分な効果が得られないことがあり、この範囲よりも高いとワイヤソーがたわみ、加工精度が低下することがある。

【００５０】また、ワイヤソーを走行させるために設けられるメインローラのうち、槽の両側に配置され、ワイヤソーの走行位置を規制する一対のメインローラにも冷却液を吐出することが好ましい。これらのメインローラに冷却液を吐出することによって、メインローラの表面に設けられている、ワイヤソーを案内するための溝を有する有機高分子層（例えばウレタンゴム層）の温度上昇を抑制するとともに、ワイヤソーまたは案内溝に付着または滞留した切削屑（またはスラッジ）を洗い流すことによって、ワイヤソーの走行位置がずれたり、ワイヤソーが溝から外れたりするのを防止することができる。

【００５１】また、切削工程で生成された、希土類合金の切削屑を含むスラッジと冷却液とからなるダーティ液を回収し、スラッジのなかから希土類合金の切削屑を磁石を用いて分別することによって、冷却液を再利用（例えば、循環的に使用）することができる。上述したように、水を主成分とする冷却液は粘度が低いので、切削屑を容易に分別することができる。また、希土類合金の切削屑を分別することによって、冷却液の廃液処理を容易に且つ環境にダメージを与えないように実施することができる。さらに、切削屑を希土類合金の再生原料として利用することもできる。冷却液は水を主成分とするので、切削屑から再生された希土類合金に含まれる炭素の量を低くすることが容易なので、希土類磁石の材料として用いられる原料を得ることができる。スラッジからの切削屑の分別方法は、例えば、本願出願人が特願２０００－２２４４８１号に開示した方法を用いることができる。

【００５２】本発明による切断方法は、上述したように、切断が難しい希土類焼結合金、特に、Ｒ－Ｆｅ－Ｂ系希土類焼結合金の切断に好適に適用される。本発明による切断方法によって切断された希土類合金を着磁することによって、希土類磁石が得られる。着磁工程は、切削工程の前に行ってもよいし、後に行ってもよい。Ｒ－Ｆｅ－Ｂ系希土類焼結合金を用いて製造される希土類焼結磁石は、磁気ヘッドの位置決めに用いられるボイスコイルモータ用の材料として好適に用いられる。本発明に

よる切断方法は、特に、本願出願人らによる米国特許第４，７７０，７２３号明細書および米国特許第４，７９２，３６８号明細書に開示されているＲ－Ｆｅ－Ｂ系希土類焼結磁石（合金）の切断に好適に用いられる。さらに、そのなかでも、ネオジム（Ｎｄ）、鉄（Ｆｅ）およびホウ素（Ｂ）を主成分とし、正方晶構造のＮｄ２Ｆｅ１４Ｂ金属間化合物からなる硬い主相（鉄リッチ相）と、Ｎｄリッチな粘りのある粒界相とを有する希土類焼結磁石（合金）（以下、「ネオジム磁石（合金）」と称する。）の切断および製造に好適に適用される。ネオジム磁石の代表的な例として、住友特殊金属社製、商品名ＮＥＯＭＡＸがある。

【００５３】本発明による切断方法を採用すると、希土類合金を高精度で且つ効率良く切断できるので、例えば、磁気ヘッドの位置決めに用いられるボイスコイルモータ用の小さな希土類磁石（例えば、厚さが０．５ｍｍ～３．０ｍｍ）を高精度で且つ効率良く製造することができる。

【００５４】（実施形態）以下、図面を参照しながら、本発明による希土類合金の切断方法の実施形態をさらに具体的に説明する。本実施形態では、上述のネオジム磁石の製造に用いられるネオジム磁石焼結体の切断方法を説明する。

【００５５】ネオジム（Ｎｄ－Ｆｅ－Ｂ）焼結磁石を作製する方法を簡単に説明する。なお、磁石材料としての希土類合金を作製する方法は、例えば、上述の米国特許第４，７７０，７２３号明細書および米国特許第４，７９２，３６８号明細書に詳細に開示されている。

【００５６】まず、原料金属を所定の成分比に正確に秤量した後、真空またはアルゴンガス雰囲気で高周波溶解炉にて原料金属を溶解する。溶解した原料金属を水冷の鋳型に鋳込み、所定の組成の原料合金を形成する。この原料合金を粉砕し、平均粒径３～４μｍ程度の微粉末を作製する。この微粉末を金型に入れ、磁界中でプレス成形する。このとき必要に応じて微粉末を潤滑剤と混合してからプレス成形を行う。次に、約１０００°Ｃ～約１２００°Ｃ程度の焼結工程を行えばネオジム磁石焼結体を作製することができる。この後、磁石の保磁力を向上させるために約６００°Ｃでの時効処理を実行し、希土類磁石焼結体の作製を完了する。焼結体のサイズは、例えば３０ｍｍ×５０ｍｍ×５０ｍｍである。

【００５７】得られた焼結体の切断加工を行い、焼結体から切断した複数の薄板（基板またはウェハと称される場合がある）を形成する。得られた焼結体の薄板のそれぞれに対して研磨による仕上げ加工を行い、寸法と形状を整えた後、長期的な信頼性を向上させるため、表面処理を施す。この後、着磁工程を実行した後、検査工程を経てネオジム永久磁石が完成する。なお、着磁工程を切断工程の前に行ってもよい。

【００５８】次に、本発明による切断方法を図１から図３を参照しながら説明する。

【００５９】図１は、本発明による実施形態の希土類合金の切断方法を実行するために好適に用いられるワイヤソー装置１００を示す概略構成図である。

【００６０】ワイヤソー装置１００は、３本のメインローラ１０ａ、１０ｂおよび１０ｃと、一対のリールボビン４０ａおよび４０ｂとを有している。冷却液を収容する槽３０の下部に設けられているメインローラ１０ａが駆動ローラで、槽３０の両側に設けられているメインローラ１０ｂおよび１０ｃは従動ローラである。ワイヤソー２０は、往復走行しながら、例えば、一方のリールボビン４０ａから他方のリールボビン４０ｂに巻き取られる。このとき、リールボビンの４０ａの巻き取り時間を他方のリールボビン４０ｂの巻き取り時間よりも長くすることによって、ワイヤソー２０を往復走行させながら、リールボビン４０ａ側に新しいワイヤソー２０を供給することができる。ワイヤソー２０の走行速度は、例えば、２００ｍ／ｍｉｎから１５００ｍ／ｍｉｎの範囲であり、新線を供給する速度は、例えば、０ｍ／ｍｉｎ～５ｍ／ｍｉｎの範囲である。

【００６１】メインローラ１０ａ、１０ｂおよび１０ｃの間には、ワイヤソー２０が例えば１５０列に張設される。ワイヤソー２０の走行位置を決めるために、メインローラ１０ａ、１０ｂおよび１０ｃの表面には、ワイヤソー２０を案内するための溝（例えば深さ約０．６ｍｍ、不図示）を有する有機高分子層（例えばウレタンゴム層）が設けられている。ワイヤソー２０の列間の間隔は、この案内溝のピッチによって決められる。案内溝のピッチは、ワークから切り出すべき板の厚さに応じて設定される。

【００６２】リールボビン４０ａおよび４０ｂの近傍には、巻き取り位置を調整するためのトラバーサ４２ａおよび４２ｂがそれぞれ設けられている。リールボビン４０ａおよび４０ｂからメインローラ１０ａに至るまでの経路中には、それぞれの側に５つのガイドローラ４４と、１つのテンションローラ４６とが設けられており、ワイヤソー２０を案内するとともに、その張力が調整される。ワイヤソー２０の張力は、種々の条件（切削長、切断速度、走行速度など）に応じて適宜変更され得るが、例えば２０Ｎ～４０Ｎの範囲に設定される。

【００６３】上述したようにして作製された焼結体ワーク５０は、以下の様にして、ワイヤソー装置１００にセットされる。

【００６４】複数のワーク５０は、例えばエポキシ系の接着剤（不図示）によって相互に固着され、複数のブロックとして組み立てられ状態で、炭素ベースプレート５２を間に介して、鉄製のワークプレート５４に固定される。ワークプレート５４、ワーク５０の各ブロックおよび炭素ベースプレート５２も接着剤（不図示）によって互いに固着されている。炭素製ベースプレート５２は、

ワーク５０の切断加工が終了した後、ワークプレート５４の下降動作が停止するまでワイヤソー２０による切断加工を受け、ワークプレート５４を保護するというダミーとして機能する。

【００６５】本実施形態では、ワイヤソー２０の走行方向に沿って計測した各ブロックのサイズが１００mm程度になるように各ブロックの大きさを設計している。従って、ここでは、ワイヤソー２０による切削長さは、約２００mmである。本実施形態では上述のようにワーク５０を複数のブロックに分割して配置しているが、ワイヤソー２０の走行方向におけるサイズをどの程度の大きさに設定すべきかは、冷却液の表面張力や走行速度によっても変化する。また、各ワーク５０の大きさによって、ひとつのブロックを構成するワーク５０の数や配置も変化する。これらを考慮して、適宜最適なサイズのブロックに分けてワーク５０を配置すればよい。

【００６６】上述のようにセットされたワーク５０は、モータ５８を備える昇降装置によって下降され、走行するワイヤソー２０に押し付けられ、切削加工される。ワーク５０の下降速度は、種々の条件に応じて変化し得るが、例えば、２０mm／ｈｒ～５０mm／ｈｒの範囲内に設定される。

【００６７】冷却液タンク６０に貯蔵されている冷却液は、吐出ポンプ６２によって、配管６３を介して圧送される。配管６３は、途中で、下部配管６４と上部配管６６とに分岐されている。下部配管６４および上部配管６６には、それぞれへの冷却液の流量を調整するためのバルブ６３ｂおよび６３ａが設けられている。下部配管６４は、切削部を浸漬するための槽３０の底部に設けられた下部ノズル６４ａに接続されている。上部配管６６は、槽３０の開口部から冷却液を供給するための上部ノズル６６ａ、６６ｂおよび６６ｃと、メインローラ１０ｂおよび１０ｃをそれぞれ冷却するために設けられた上部ノズル６６ｄおよび６６ｅとに接続されている。

【００６８】槽３０には、上部ノズル６６ａ、６６ｂおよび６６ｃと下部ノズル６４ａとから冷却液が供給され、少なくとも切削工程の間は、図１中に矢印Ｆで示したように、冷却液が槽３０の開口部から溢れ出る状態に維持される。槽３０から溢れ出た冷却液は、槽３０の下方に設けられた回収用パン７０によって回収タンク７２に導かれ、蓄積される。回収された冷却液は、例えば図１に示したように、吐出ポンプ７４によって循環用配管７６を介して、冷却液タンク６０に送られる。循環用配管７６の途中には、フィルタ７８が設けられており、回収された冷却液中の切削屑が分別除去される。回収方法は、これに限られず、磁力を利用して切削屑を分別する機構を設けてもよい（例えば特願２０００－２２４４８１号参照）。

【００６９】次に、図２を参照しながら、本発明による切断工程をさらに詳細に説明する。

【００７０】槽３０は、ワイヤソー２０の走行方向と交差する側壁の開口部付近に補助壁３２を有している。この補助壁３２は、プラスチック板（例えばアクリル板）で形成されており、図２中に破線で示した無負荷時におけるワイヤソーの走行位置と近接するように設けられている。切断するためにワーク５０を下降し、ワイヤソー２０に接触させるとワイヤソー２０はたわみ、図２中に実線で示したように、槽３０内の冷却液に切削部が浸漬された状態となる。このとき、ワイヤソー２０がたわむに連れて、ワイヤソー２０は補助壁３２を切削し、スリットを形成する。ワイヤソー２０による切削が定常状態になると、たわみ量は一定し、ワイヤソー２０は補助壁３２に形成されたスリット内を通過しながら、ワーク５０を切削する。従って、補助壁３２に形成されたスリットは、ワイヤソー２０の走行位置を規制するように機能し、加工精度の安定にも寄与する。

【００７１】槽３０は、例えば約３５Ｌ（リットル）の容量を有しており、切削工程中は、下部ノズル６４ａから約３０Ｌ／ｍｉｎの流量で冷却液が供給され、上部ノズル６６ａ、６６ｂおよび６６ｃから約９０Ｌ／ｍｉｎの流量で冷却液が供給され、常に冷却液が開口部から溢れ出る状態に維持される。ワイヤソー２０に冷却液を供給することだけを考えると、図２に示したように、切削中はワイヤソー２９がたわむので、冷却液を溢れさせる必要は必ずしも無いが、例示するネオジム磁石焼結体を切断するときには切削屑の排出性を向上するために、上記のような構成を採用することが好ましい。

【００７２】切削屑の排出性を高めるためには、切削部付近の冷却液内に含まれる切削屑の量を減らすことが有効である。十分な排出性を得るためには、冷却液が１分間に溢れ出る量は、槽の容積の５０％以上であることが好ましい。さらに、新鮮な冷却液は、槽３０の底部よりも開口部から多く供給することが好ましい。水を主成分とする粘度の低い冷却液を用いているので、冷却液中に排出された切削屑は容易に沈降するので、槽３０の底部から多くの冷却液を供給すると、沈降した切削屑が切削部近傍に浮遊する原因となるので好ましくない。

【００７３】また、開口部からワイヤソー２０（つまり切削溝）に供給される新鮮な冷却液が占める割合を多くするために、走行するワイヤソー２０よりも上方から供給される冷却液を多くすることが好ましい。すなわち、槽３０の開口部からも冷却液を供給し、開口部から溢れる状態に維持することによって、切削部に供給される冷却液に含まれる切削屑の量を低下させることができる。さらに、槽３０の開口部から供給される冷却液の流れによって、ワイヤソー２０に付着した切削屑を機械的に洗い流す効果も得られる。

【００７４】また、上述した補助壁３２は、ワイヤソー２０によって形成されたスリット以外の部分は、槽３０の側壁として機能するので、冷却液の液面Ｓを高く保つ

ように機能する。さらに、槽３０の開口部のワイヤソー２０の走行方向と交差する辺に、ノズル６６ｂおよび６６ｃを用いて、カーテン状の冷却液流を形成し、冷却液が槽３０の開口部から溢れ出るのを抑制する。これにより、溢れ出る冷却液の液面Ｓを槽３０の補助壁３２よりも高くすると、より多くの冷却液が切削部の周囲に供給されることになるので、冷却液中の切削屑の量をさらに低下させることができる。冷却液流を形成するための吐出圧は、２０ＭＰａ（２ｋｇｆ）～１００ＭＰａ（１０ｋｇｆ）の範囲内にあることが好ましく、４０ＭＰａ（４ｋｇｆ）～６０ＭＰａ（６ｋｇｆ）の範囲内にあることがさらに好ましい。この範囲よりも吐出圧が低いと充分な効果が得られないことがあり、この範囲よりも高いとワイヤソー２０にぶれが発生し、その結果、加工精度が低下することがある。

【００７５】また、槽３０の両側に配置され、ワイヤソー２０の走行位置を規制する一対のメインローラ１０ｂおよび１０ｃにも冷却液を吐出することが好ましい。これらのメインローラ１０ｂおよび１０ｃに冷却液を吐出することによって、メインローラ１０ｂおよび１０ｃの表面に設けられている、ワイヤソー２０を案内するための溝を有する有機高分子層（例えばウレタンゴム層）の温度上昇を抑制するとともに、ワイヤソー２０または案内溝に付着または滞留した切削屑（またはスラッジ）を洗い流すことができるので、ワイヤソー２０の走行位置がずれたり、ワイヤソー２０が溝から外れたりするのを防止することができるとともに、排出性を向上する効果も得られる。

【００７６】水を主成分とする冷却液に混合される極圧添加剤としては、硫黄含有化合物が好ましい。硫黄含有化合物の中でも、硫化脂肪酸、メルカプト脂肪酸、チオカルボン酸、ポリスルフィドのα、ωジカルボン酸などの有機酸およびこれらの塩やメルカプトアルコールなどが好ましい。

【００７７】硫化脂肪酸としては、オレイン酸、リノール酸などの不飽和脂肪酸の硫化物を用いることができる。脂肪酸の炭素数が８～２２のものが好ましい。メチルカプト脂肪酸としては、チオグリコール酸、１２－メルカプトステアリン酸を用いることができる。チオカルボン酸としては、チオ安息香酸、ジチオ安息香酸を用いることができ、ポリスルフィドのα、ωジカルボン酸としては、ジチオプロピオン酸、ジチオオクチル酸を用いることができる。これらの酸と塩を形成する塩基としては、アルカノールアミン、アルキルアミン、アンモニアおよび無機アルカリ化合物を用いることができる。メルカプトアルコールとしては、メルカプトエタノール、メルカプトプロパノール、メルカプトイソブタノールを用いることができる。

【００７８】水を主成分とする冷却液に添加される界面活性剤としては、アニオン系として、脂肪酸石鹸やナフテン酸石鹸等の脂肪酸誘導体、又は長鎖アルコール硫酸エステルや動植物油の硫酸化油等の硫酸エステル型、又は石油スルホン酸塩等のスルホン酸型、非イオン系として、ポリオキシエチレンアルキルフェニルエーテルやポリオキシエチレンモノ脂肪酸エステル等のポリオキシエチレン系、ソルビタンモノ脂肪酸エステル等の多価アルコール系、又は脂肪酸ジエタノールアミド等のアルキロールアミド系を用いることができる。具体的には、ケミカルソリューションタイプのＪＰ－０４９７Ｎ（カストロール社製）を水に２重量％程度添加することによって、表面張力および動摩擦係数を所定の範囲内に調整することができる。

【００７９】また、シンセティックタイプ合成潤滑剤としては、シンセティック・ソリューションタイプ、シンセティック・エマルションタイプおよびシンセティックソリュブルタイプを用いることができ、そのなかでも、シンセティック・ソリューションタイプが好ましく、具体的には、グリコールおよびアルカノールアミン等を含む潤滑剤（ユシロ化学工業社製の＃８３０および＃８７０）や、シンタイロ９９５４（カストロール社製）を挙げることができる。いずれも、水に２重量％～１０重量％程度添加することによって、表面張力（または動摩擦係数）を好適な範囲内に調整することができる。

【００８０】また、錆止め剤を含有させることで、希土類合金の腐食を防止することができる。ここで、ＰＨは８～１１とすることが好ましい。錆止め剤としては、有機系として、オレイン酸塩や安息香酸塩等のカルボン酸塩、又はトリエタノールアミン等のアミン類、無機系として、りん酸塩、ホウ酸塩、モリブデン酸塩、タングステン酸塩、又は炭酸塩を用いることができる。

【００８１】また、非鉄金属防食剤としては、例えばベンズトリアゾール等の窒素化合物を、防腐剤としては、ヘキサハイドロトリアジン等のホルムアルデヒド供与体を用いることができる。

【００８２】また消泡剤としては、シリコーンエマルジョンを用いることができる。消泡剤を含有させることで、冷却液の泡立ちを少なくし、冷却液の浸透性をよくし、冷却効果を高め、ワイヤソー２０での温度上昇を防ぎ、ワイヤソー２０の温度の異常上昇や異常摩耗が起こりにくくなる。

【００８３】図３を参照しながら、本実施形態で好適に用いられるワイヤソー２０の構造を説明する。なお、図中では、ワイヤソー２０の一点鎖線で示した中央線から下半分は簡略化している。

【００８４】ワイヤソー２０としては、芯線（ピアノ線）２２の外周面にダイヤモンド砥粒２４を樹脂層２６で固着したものが好適に用いられる。そのなかでも、樹脂としてフェノール樹脂を用いることが好ましい。フェノール樹脂は、ピアノ線（硬鋼線）２２の外周面への接着強度が高く、また上述した冷却液に対する濡れ性（浸

透性）にも優れる。

【００８５】好適なワイヤソー２０の具体例としては、直径が約０．１８ｍｍのピアノ線２２の外周に、平均粒径が約４５μｍのダイヤモンド砥粒を、フェノール樹脂層２６で固着し、外径が約０．２４ｍｍのワイヤソー２０が挙げられる。また、切削効率と切削屑（スラッジ）の排出効率の観点から、ワイヤソー２０の走行方向（軸方向：図中の一点破線に平行な方向）における、互いに隣接する砥粒２６間の平均距離は、砥粒の平均粒径Ｄの２００％～６００％の範囲内にあるものが好ましい。さらに、砥粒２２がフェノール樹脂層２６の表面から突出している部分の平均高さは、１０μｍ～４０μｍの範囲内にあることが好ましい。このようなワイヤソー２０は、砥粒２２間に適度な大きさの空間（「チップポケット」と呼ばれることもある）２８が形成されているので、良好な切削効率を有するとともに、良好な排出性を有する。

【００８６】ここで、極圧添加剤として硫化オレイン酸ジエタノールアミン塩を含む冷却液について、希土類合金の切断特性に与える極圧添加剤の添加量依存性を検討＊した結果の例を説明する。

【００８７】切断には図１に示したワイヤソー装置１００を用いた。ワイヤソー２０としては、直径１８０μｍの芯線に、粒径４０μｍ～６０μｍの工業用ダイヤモンド砥粒が厚さ１５μｍ～４０μｍのフェノール樹脂層で固定されたワイヤソーを用いた。砥粒間の平均距離は約１００μｍであった。

【００８８】ワークとしては、住友特殊金属株式会社製のＮＥＯＭＡＸ－４６を用い、切削溝の長さは２００ｍｍとし、ワークの降下速度を４０ｍｍ／ｈで一定に保った状態で、ワイヤソー２０にかかる張力Ｆｘ（ワイヤソー２０の走行方向）と降下方向に対する反力（Ｆｚ）を水晶圧電式ロードセルを用いて測定した。

【００８９】冷却水として、まず、水（水道水）にユシロ化学工業社製のシンセティックタイプ合成潤滑剤＃８３０を１０体積％混合したものを用意した。これに硫化オレイン酸ジエタノールアミン塩を表１に示す量（体積基準）を添加したものを冷却液として用いた。

【００９０】

【表１】

極圧添加剤濃度（ppm）	0	500	1000	2000
切断速度（mm/H）	24.6	29.3	35.7	33.1
切断抵抗：ワイヤ１本あたり				
Fx 張力（N）	0.95	1.13	0.97	0.84
Fz 仕事量（N·mx10^{-3}）	319.8	351.5	353.0	301.9
切断速度換算				
Fx 張力（N）	1.38	1.38	0.97	0.91
Fz 仕事量（N·mx10^{-3}）	464.1	428.3	353.0	325.6

【００９１】表１の結果から明らかなように、極圧添加剤を５００ｐｐｍ以上添加することによってＦｘおよびＦｘともに低下している。この切断抵抗の低下傾向は２００００ｐｐｍ程度まで確認されたが、２００００ｐｐｍを超えると一部のワークに腐食が見られた。また、切断抵抗の低下は、１０００ｐｐｍから５０００ｐｐｍの範囲でほぼ飽和する傾向が見られた。これらのことから、冷却水に対する極圧添加剤の添加量は、２００００ｐｐｍ以下であることが好ましく、１０００ｐｐｍ以上５０００ｐｐｍ以下であることがさらに好ましいと言える。

【００９２】

【発明の効果】本発明によると、水を主成分とする冷却液を用いて実行できる、固定砥粒ワイヤソーによる希土類合金の切断方法が提供される。

【００９３】本発明の切断方法を用いると、高い加工精度で、且つ、少ない切削しろで、希土類合金を切断することができるので､高価な希土類金属合金の材料のロスを軽減することができる。また、冷却液の循環使用を容易に実現できるので、環境に優しく、また、廃液の処理のコストを低減することができる。従って、希土類金属合金の加工コストが低減され、切断品、例えば、磁気ヘッド用のボイスコイルモータを低価格で製造することができる。

【図面の簡単な説明】

【図１】本発明による実施形態の希土類合金の切断方法を実行するために好適に用いられるワイヤソー装置１００を示す模式図である。

【図２】図１に示したワイヤソー装置１００の切削部近傍の構成を示す模式図である。

【図３】本発明による実施形態の希土類合金の切断方法を実行するために好適に用いられるワイヤソー２０の断面構造を模式的に示す図である。

【符号の説明】

１０ａ、１０ｂ、１０ｃ　メインローラ

２０　ワイヤソー

３０　槽

４０ａ、４０ｂ　リールボビン

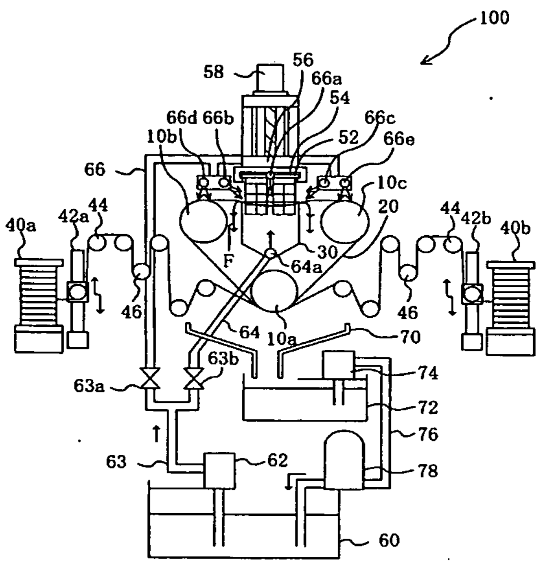
19

４２ａ、４２ｂ　トラバーサ
５０　ワーク

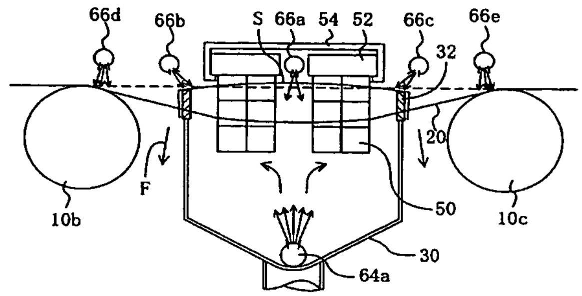
20

６０　冷却液タンク
７０　回収用パン

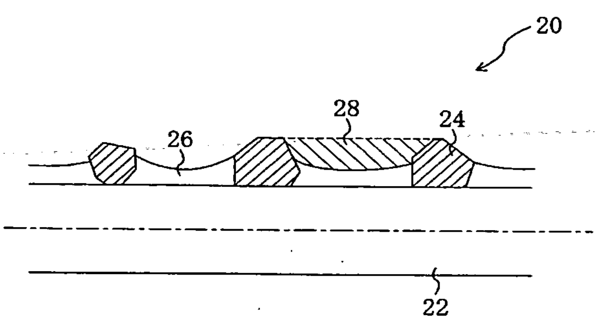
【図１】



【図２】



【図３】



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Ｆターム(参考)　3C058 AA05 AC04 CA04 CB10 DA12

CLAIMS

[Claim(s)]
[Claim 1] Cutting process of a rare earth alloy with which it is the cutting process of the rare earth alloy using the wire saw which made the core wire fix an abrasive grain, the process which cuts said rare earth alloy by making it run said wire saw where said rare earth alloy is immersed [water] in the coolant used as a principal component in the part cut by said wire saw is included, and said coolant contains 500 ppm or more an extreme pressure additive 20000 ppm or less on volume criteria.
[Claim 2] Said extreme pressure additive is a cutting process of a rare earth alloy according to claim 1 which is a sulfur content compound.
[Claim 3] The surface tension in 25-degreeC of said coolant is a cutting process of a rare earth alloy according to claim 1 or 2 which is within the limits of 25 mN/m - 60 mN/m.
[Claim 4] Said coolant is the cutting process of a rare earth alloy given in either containing the water of the weight within the limits of 10 times to 50 times of the weight of water-soluble synthetic lubricant and said synthetic lubricant of claims 1-3.
[Claim 5] Said coolant is the cutting process of a rare earth alloy given in either containing the water of the weight within the limits of 10 times to 50 times of the weight of a surfactant and a surfactant of claims 1-3.
[Claim 6] Said coolant is the cutting process of a rare earth alloy given in either of claims 1-5 containing a defoaming agent.
[Claim 7] Said coolant is the cutting process of a rare earth alloy given in either of claims 1-6 whose PHs are 8-11.
[Claim 8] Said coolant is the cutting process of a rare earth alloy given in either of claims 1-7 containing a rusr-proofer.
[Claim 9] Said abrasive grain is the cutting process of a rare earth alloy given in either of claims 1-8 which has fixed by the phenol resin layer formed in the peripheral face of said core wire.

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[Claim 10] The average height of the part which the mean distance between said abrasive grains which adjoin mutually has within the limits of 200% - 600% of the mean particle diameter of said abrasive grain, and said abrasive grain has projected from the front face of said phenol resin layer in the transit direction of said wire saw is the cutting process of a rare earth alloy given in either of claims 1-9 which is within the limits of 10 micrometers - 40 micrometers.
[Claim 11] The mean particle diameter D of said abrasive grain is the cutting process of a rare earth alloy given in either of claims 1-10 which satisfies 20 micrometer<=D <=60micrometer relation.
[Claim 12] It is the cutting process of a rare earth alloy given in either of claims 1-11 which is maintained by the condition of overflowing from said opening by being supplied from opening of said tub, by being immersed in said coolant by which the part in which said rare earth alloy is cut by said wire saw was held in the tub in said cutting process while said coolant is supplied in said tub from the pars basilaris ossis occipitalis of said tub.
[Claim 13] The amount in which said coolant overflows in 1 minute in said cutting process is a cutting process of a rare earth alloy according to claim 12 which is 50% or more of the volume of said tub.
[Claim 14] The amount of said coolant supplied from said opening in said cutting process is more cutting process of a rare earth alloy according to claim 10 or 13 than the amount of said coolant supplied from said pars basilaris ossis occipitalis.
[Claim 15] Cutting process of a rare earth alloy given in either of claims 12-14 which controls that said coolant overflows from said opening of said tub in said cutting process by forming curtain-like an air current or a cooling liquid flow in said opening of said tub.
[Claim 16] Said rare earth alloy is the cutting process of a rare earth alloy given in either of claims 1-15 which are R-Fe-B system rare earth sintered alloys.
[Claim 17] Said rare earth alloy is the cutting process of the rare earth alloy according to claim 16 which is a Nd-Fe-B system rare earth sintered alloy.
[Claim 18] The manufacture approach of the rare earth magnet which includes the process which produces the sintered compact of a rare earth magnet from rare earth alloy powder, and the process which separates two or more rare earth magnets into either of claims 1-17 from said sintered compact using the cutting process of the rare earth alloy of a publication.
[Claim 19] A voice coil motor equipped with the rare earth magnet produced by the manufacture approach of a rare earth magnet according to claim 18.
[Claim 20] The voice coil motor according to claim 19 in the range whose thickness of said rare earth magnet is 0.5mm - 3.0mm.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] Especially this invention relates to the method of cutting a rare earth alloy using the wire saw which made the core wire fix an abrasive grain, and the manufacture approach of the rare earth magnet using it about the cutting process of a rare earth alloy, and the manufacture approach of a rare earth magnet.
[0002]
[Description of the Prior Art] The rare earth alloy is used as an ingredient of a powerful magnet, for example. The rare earth magnet obtained by magnetizing a rare earth alloy is suitably used as a magnet for voice coil motors used for positioning of the magnetic head of a magnetic recording medium.
[0003] The technique which slices an ingot from the former as an approach of cutting the ingot (a sintered compact being included) of a rare earth alloy, using the slicing blade rotated, for example is adopted. However, according to the approach of cutting with a slicing blade, since the thickness of a cutting cutting edge is comparatively large, a chipping allowance increases, and the yield of a rare earth alloy ingredient is low, and has become the factor which raises the cost of a rare earth alloy product (for example, rare earth magnet).
[0004] There is an approach using the wire saw as a cutting process with few finishing allowances than a slicing blade. For example, JP,11-198020,A is indicating that hard and brittle materials, such as silicon, glass, neodymium, and a ferrite, can be cut using the wire saw (it is called a "bonded abrasive wire".) which fixed superabrasive by the bond layer on the peripheral surface of the core wire of high intensity.
[0005]
[Problem(s) to be Solved by the Invention] If the plate of predetermined thickness is producible from the ingot of a rare earth alloy to several multi-sheet coincidence by few

chipping allowances using the above bonded abrasive wire saws, the manufacturing cost of a rare earth magnet will be reduced sharply. However, there is still no report that the rare earth alloy was cut on mass-production level using the bonded abrasive wire saw.
[0006] It is mentioned that the mechanical property of a rare earth alloy and the rare earth alloy (a "rare earth sintered alloy" is called hereafter.) especially manufactured by the sintering process differs from silicon etc. greatly as this main cause from the result which the artificer examined variously. Since it has the hard main phase (R2Fe14 B phase) which causes brittleness--mainly destruction, and the grain boundary phase (R rich phase) which causes ductility-destruction, specifically, unlike the hard and brittle material represented by silicon, a rare earth sintered alloy is hard to be cut. That is, compared with the case where hard and brittle materials, such as silicon, are cut, cutting force is high, consequently calorific value also has it. [much] Moreover, the specific gravity of a rare earth alloy is large compared with ingredients, such as about 7.5 and silicon, and the cutting waste (sludge) generated by cutting is hard to be discharged from the cutting section.
[0007] Therefore, in order to cut a rare earth alloy efficiently with high process tolerance, while fully reducing cutting force, heat is efficiently radiated in the heat generated at the time of cutting, namely, it is necessary to cool the cutting section efficiently. Moreover, it is necessary to discharge efficiently the cutting waste generated by cutting.
[0008] While falling cutting force by fully supplying the coolant (it also being called "cutting fluid".) excellent in lubricity to the cutting section of a rare earth alloy, the heat generated at the time of cutting can be radiated efficiently. If the wire saw is soaked in sufficient quantity of the coolant using the oily coolant as a result of the experiment by the artificer, the coolant can fully be supplied to the narrow cutting section by the wire saw it runs.
[0009] However, in order to process waste fluid so that environmental destruction may not be caused, it is difficult for the oily coolant that cost starts and to classify the cutting waste in waste fluid, and there is a problem that reuse of waste fluid or cutting waste is difficult. Moreover, in case cutting waste is reused, the carbon content in a raw material increases, and in order to reduce magnetic properties, there is also a problem of not being desirable. If these things are taken into consideration, as coolant, water (or water-soluble coolant) is desirable, but if water is used as coolant, since amount sufficient since viscosity (1.0mm2/s) is low for the wire saw it runs cannot be made to adhere, even if water wets a wire saw with water, it cannot supply the water of sufficient amount for the cutting section.
[0010] By making it run a wire saw in the coolant overflowed from the tub of the coolant, JP,11-198020,A is indicating that the coolant can be made to adhere to a wire saw certainly, when making it run a bonded abrasive wire saw at high speed (for example,

2000 m/min). However, according to the experiment of this invention person, even if it cuts a rare earth alloy, making it run a wire saw (for example, indicated by JP,11-198020,A) in the water currently overflowed, omission of an abrasive grain, and in being severe, an open circuit of a wire saw occurs. The travel speed of a wire saw generated this fault also for example, in 800 m/min extent. Even if it adopts the above-mentioned approach, this has high cutting force and is considered because water is not fully supplied to the cutting section.

[0011] This invention is made in view of these many points, and the main purpose is in offering the cutting process of the rare earth alloy by the bonded abrasive wire saw which can be performed using the coolant which uses water as a principal component. Moreover, other purposes of this invention are to offer the voice coil motor equipped with the manufacture approach of a rare earth magnet of having used the cutting process of the above-mentioned rare earth alloy, and the rare earth magnet concerned. [0012] [Means for Solving the Problem] It is in the condition to which the cutting process of the rare earth alloy by this invention is the cutting process of the rare earth alloy using the wire saw which made the core wire fix an abrasive grain, and said rare earth alloy was immersed [water] in the coolant used as a principal component in the part cut by said wire saw. By making it run said wire saw, the process which cuts said rare earth alloy is included, it is characterized by said coolant containing 500 ppm or more an extreme pressure additive 20000 ppm or less on volume criteria, and the above-mentioned purpose is attained by that.

[0013] As for said extreme pressure additive, it is desirable that it is a sulfur content compound.

[0014] As for the surface tension in 25-degreeC of said coolant, it is desirable that it is within the limits of 25 mN/m - 60 mN/m.

[0015] As for said coolant, it is desirable that the water of the weight within the limits of 10 times to 50 times of the weight of water-soluble synthetic lubricant and said synthetic lubricant is included.

[0016] Or said coolant may also contain the water of the weight within the limits of 10 times to 50 times of the weight of a surfactant and a surfactant.

[0017] Said coolant may also contain a defoaming agent. As for said coolant, it is desirable that PHs are 8-11. Moreover, said coolant may also contain a rusr-proofer.

[0018] As for said abrasive grain, it is desirable to have fixed by the phenol resin layer formed in the peripheral face of said core wire.

[0019] As for the average height of the part which the mean distance between said abrasive grains which adjoin mutually has within the limits of 200% - 600% of the mean particle diameter of said abrasive grain, and said abrasive grain has projected from the front face of said phenol resin layer in the transit direction of said wire saw, it is desirable

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that it is within the limits o[illegible]0 micrometers - 40 micromete[illegible].
[0020] As for the mean particle diameter D of said abrasive grain, it is desirable to satisfy 20 micrometer<=D <=60micrometer relation.
[0021] In said cutting process, it is immersed in said coolant by which the part in which said rare earth alloy is cut by said wire saw was held in the tub, and being maintained by the condition of overflowing from said opening is desirable [the coolant] by being supplied from opening of said tub while said coolant is supplied in said tub from the pars basilaris ossis occipitalis of said tub.
[0022] As for the amount in which said coolant overflows in 1 minute, in said cutting process, it is desirable that it is 50% or more of the volume of said tub.
[0023] In said cutting process, many things of the amount of said coolant supplied from said opening are more desirable than the amount of said coolant supplied from said pars basilaris ossis occipitalis.
[0024] In said cutting process, it is desirable by forming curtain-like an air current or a cooling liquid flow in said opening of said tub to control that said coolant overflows from said opening of said tub.
[0025] Said rare earth alloy may be a R-Fe-B system rare earth sintered alloy, and may be a Nd-Fe-B system rare earth sintered alloy. In addition, R is the rare earth elements containing Y.
[0026] The manufacture approach of the rare earth magnet of this invention includes the process which produces the sintered compact of a rare earth magnet from rare earth alloy powder, and the process which separates two or more rare earth magnets from said sintered compact using the cutting process of one of the above-mentioned rare earth alloys, and the above-mentioned purpose is attained by that.
[0027] The voice coil motor by this invention is equipped with the rare earth magnet produced by the manufacture approach of the above-mentioned rare earth magnet. The thickness of said rare earth magnet may be in the range which is 0.5mm - 3.0mm.
[0028]
[Embodiment of the Invention] Below, the cutting process of the rare earth alloy of the operation gestalt by this invention and the manufacture approach of a rare earth magnet are explained.
[0029] The cutting process of the rare earth alloy by this invention is the cutting process of the rare earth alloy using the wire saw which made the core wire (typically piano wire) fix an abrasive grain (typically diamond abrasive grain), while a rare earth alloy supplies the coolant which uses water as a principal component to the part cut by the wire saw, by making it run a wire saw, the process which cuts a rare earth alloy is included and the coolant contains 500 ppm or more an extreme pressure additive 20000 ppm or less on volume criteria. As for an extreme pressure additive, it is desirable that it is a sulfur

content compound. In addition, in this specification, "the coolant which uses water as a principal component" means the coolant whose 70% of the weight or more of the whole is water.
[0030] With the frictional heat generated at the time of cutting, an extreme pressure additive reacts chemically with the metallic element (mainly iron) which constitutes a rare earth alloy, and forms metallic compounds. Therefore, although it is hard to cut a rare earth alloy, the ductility is reduced by the extreme pressure additive, and cutting force becomes low. Therefore, even if it uses the coolant of a drainage system with low lubricity compared with the oily coolant, it becomes possible to cut a rare earth alloy efficiently.
[0031] It is desirable to use the compound (called a sulfur system extreme pressure additive) containing sulfur (S) as an extreme pressure additive. A sulfur system extreme pressure additive reacts with the iron contained in a rare earth alloy, forms an iron sulfide, and is excellent in the effectiveness of embrittling the contact surface. In addition, for example, the phosphorus system extreme pressure additive and phosphorus-sulfur system extreme pressure additive other than a sulfur system extreme pressure additive can also be used.
[0032] Although especially the sulfur content compound suitably used as an extreme pressure additive added by the coolant of this invention is not limited, what has the high compatibility (solubility or homogeneity dispersibility) over water is desirable, and it is desirable that they are an acid, a salt, or lower alcohol. For example, organic acids and these salts, such as alpha of a sulfuration fatty acid, a mercapto fatty acid, a thiocarboxylic acid, and a polysulfide and omega dicarboxylic acid, mercapto alcohol, etc. can be mentioned. Especially, alpha of a sulfuration fatty acid and a polysulfide, omega dicarboxylic acid, and these salts are desirable. A sulfur content compound may use one sort independently, and may use it combining two or more sorts.
[0033] As for the addition to the whole coolant of an extreme pressure additive, it is desirable that it is 500 ppm or more 20000 ppm or less on volume criteria, and it is still more desirable that it is [1000 ppm or more] 5000 ppm or less. When the effectiveness of an extreme pressure additive may not fully be demonstrated if it is less than 500 ppm, and it exceeds 20000 ppm, it may react beyond a rare earth alloy and the need, and dependability (corrosion resistance) may be spoiled.
[0034] Furthermore, as for the surface tension in 25-degreeC of the coolant, it is desirable that it is within the limits of 25 mN/m - 60 mN/m. As coolant, the dynamic friction coefficient in 25-degreeC to a rare earth alloy may use the thing of 0.1-0.3.
[0035] A wire saw can be efficiently cooled by performing the process which cuts a rare earth alloy using a bonded abrasive wire saw in the condition of having been immersed in the coolant which has the surface tension in 25-degreeC within the limits of about 25

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mN/m - about 60 mN/m (about 25 dyn/cm - about 60 dyn/cm) in the cutting section. Since the wettability (or concordance) to a rare earth alloy and/or a wire saw is excellent compared with water, the coolant which has the above-mentioned surface tension within the limits is the cutting section (part by which a rare earth alloy and a wire saw contact mutually, and a rare earth alloy is cut.). It is also called a cutting slot. It thinks for the coolant to permeate efficiently. Of course, since the specific heat is large compared with the oily coolant (for example, mineral oil), the coolant which uses water as a principal component has high cooling effectiveness.
[0036] The coolant suitably used in the cutting process of the rare earth alloy of this invention can also be sorted out with the dynamic friction coefficient to the above-mentioned rare earth alloy, and the coolant which has the above-mentioned dynamic friction coefficient in 25-degreeC in about 0.1 - about 0.3 within the limits can demonstrate an operation and effectiveness equivalent to the coolant which has the above-mentioned surface tension within the limits. A dynamic friction coefficient is considered to be the lubricative index which the coolant gives to the cutting section to surface tension being considered to be the index which shows the permeability of the coolant to the cutting section. In addition, it is known that a qualitative correlation is between surface tension and a dynamic friction coefficient.
[0037] The surface tension of the coolant is measured using the DEYUNUI surface tension balance known well. Moreover, dynamic coefficient of friction of the coolant to a rare earth alloy is measured in Japan using a Masuda style "a walk type friction tester" currently used abundantly as a fundamental testing machine. In this specification, each adopts the value in 25-degreeC as a value by which the coolant is characterized.
[0038] In addition, the dynamic friction coefficient shown in the following examples is the value calculated with the walk type friction tester using the iron ball. Since there are most iron contents in a component element, the R-Fe-B system rare earth alloy (for example, alloy which makes a Nd2Fe14B intermetallic compound the main phase) illustrated in the example is good approximation, and the dynamic friction coefficient of the coolant for which it asked using the iron ball can be used for it as a dynamic friction coefficient to a rare earth alloy. The presentation and the manufacture approach of a rare earth alloy which are suitably used as a rare earth magnet are indicated by U.S. Pat. No. 4,770,723 and U.S. Pat. No. 4,792,368.
[0039] In addition, although the coolant suitably used with the cutting process of this invention was specified using the surface tension or the dynamic friction coefficient of 25-degreeC, the temperature of the coolant at the time of actually using it is not restricted to 25-degreeC. However, in order to acquire the effectiveness of this invention, it is desirable to use the coolant by which temperature control was carried out within the limits of 15-degreeC-35-degreeC, it is still more desirable that it is within the limits of

20-degreeC-30-degreeC, and it is still more desirable that it is within the limits of 20-degreeC-25-degreeC. Since it depends for the surface tension and the dynamic friction coefficient of the coolant on temperature as known well, if it separates not much from the temperature requirement of the above [the temperature of the actually used coolant], the surface tension and the dynamic friction coefficient of the coolant will be in the condition of having resembled well the condition of having separated from the above-mentioned numerical range, respectively, and cooling effectiveness will fall.
[0040] Since the abnormality rise of the temperature of a wire saw can be controlled by using the coolant which has the surface tension (or dynamic friction coefficient) of the above-mentioned range, abnormality degraining of an abrasive grain and an open circuit of a wire saw can be controlled and prevented still more efficiently. Consequently, while the fall of process tolerance is prevented, since it becomes possible to use a wire saw for a period longer than before, a manufacturing cost can be reduced.
[0041] The coolant which has the surface tension (or dynamic friction coefficient) of the above-mentioned range is prepared by adding in water a surface active agent and the so-called synthetic lubricant called "synthetic [synthetic (Synthetic)]." By adjusting a class and an addition, predetermined surface tension and a predetermined dynamic friction coefficient can be obtained. Moreover, since viscosity is comparatively low when the coolant which uses water as a principal component is used, it is possible to classify the cutting waste of a rare earth alloy from the sludge generated by cutting easily using a magnet, and the coolant can be reused. Moreover, it can prevent having a bad influence on natural environment by abandonment processing of the coolant. Moreover, the amount of the carbon contained in a sludge can be reduced and the magnetic properties of the magnet which uses as a raw material the cutting waste collected from the sludge can be improved.
[0042] When it cuts making it run a wire saw at high speed, the coolant may foam and cooling effectiveness may fall. By using the coolant containing a defoaming agent, decline in the cooling effectiveness by foaming of the coolant can be controlled. Furthermore, the corrosion of a rare earth alloy can be controlled by using the coolant which has PH within the limits of 8-11. Moreover, oxidation of a rare earth alloy can be controlled by using the coolant containing a rusr-proofer. What is necessary is just to adjust these suitably in consideration of a class, cutting conditions, etc. of a rare earth alloy.
[0043] As a wire saw, what fixed the diamond system abrasive grain by resin is used suitably. That is, the wire saw which used resin and fixed the diamond system abrasive grain to the peripheral face of a core wire (typically piano wire) can be used suitably. Also in it, it is desirable to use phenol resin as resin. The bond strength of phenol resin to the peripheral face of piano wire (hard drawn steel wire) is high, and it excels also in the

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wettability (permeability) to the coolant mentioned later. Moreover, it is cheaper than the wire saw manufactured using an electrodeposition process, and the cost concerning cutting of a rare earth alloy can be reduced. Although the fixing force of an abrasive grain is weak compared with the wire saw produced by the electrodeposition process (an abrasive grain is fixed for example, with nickel plating etc.), since peeling of an abrasive grain etc. can be lessened by using the coolant adjusted to the range which mentioned the dynamic friction coefficient above, it becomes possible to cut the rare earth alloy which is hard to cut.

[0044] In addition, the core wire of a wire saw may not be restricted to piano wire, but may be formed from what bundled high intensity fiber, such as a thing formed from refractory metals, such as alloys, such as nickel-Cr and Fe-nickel, W, and Mo, or nylon fiber. Moreover, the ingredient of an abrasive grain may not be limited to a diamond, but may be SiC, B, C, CBN (Cubic Boron Nitride), etc.

[0045] In order to acquire the advantage that it cuts and there is little **, the outer diameter of a wire saw has 0.3 desirablemm or less, and it is still more desirable that it is 0.25mm or less. In order that it may be set up and the lower limit of the outer diameter of a wire saw may fix the abrasive grain of predetermined magnitude by sufficient reinforcement so that sufficient reinforcement may be obtained, a core wire with a diameter of about 0.12-0.20mm is used. As for the mean particle diameter D of an abrasive grain, it is desirable to satisfy 20 micrometer<=D <=60micrometer relation from a viewpoint of a cutting efficiency, and it is desirable to satisfy especially the relation which is 40 micrometer<=D <=60micrometer. Moreover, as for the mean distance between the abrasive grains which adjoin mutually in the transit direction of the viewpoint of a cutting efficiency and the discharge effectiveness of cutting waste (sludge) to a wire saw, it is desirable that it is within the limits of 200% - 600% of the mean particle diameter D of an abrasive grain, and, as for the average height of the part which the abrasive grain has projected from the front face of a phenol resin layer, it is desirable that it is within the limits of 10 micrometers - 40 micrometers. this wire saw may be supplied by the manufacturer (for example, incorporated company ally DOMATE -- real) of a general wire saw if the above-mentioned specification is specified.

[0046] Since a good cutting efficiency can be realized and it excels also in eccritic [of cutting waste] when such a wire saw is used, it can cut also at a comparatively high travel speed (for example, 1000 m/min). Moreover, since it is efficiently cooled by the above-mentioned coolant, with good process tolerance, it can continue at a long period of time, and a rare earth alloy can be cut to stability.

[0047] The coolant which uses as a principal component the water used for the cutting process of this invention is one with low (kinematic viscosity is about 1mm2/s) viscosity, and eccritic [of cutting waste] is lower than the oily coolant (kinematic viscosity is

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generally more than 5mm2/s. Then, it is maintained by the condition of having been immersed in the coolant by which the cutting section was held in the tub in the cutting process in order to raise eccritic [of cutting waste], and being maintained by the condition of overflowing from opening of a tub is desirable [the coolant] by being supplied from opening of a tub while the coolant is supplied in a tub from the pars basilaris ossis occipitalis of a tub.

[0048] The cutting waste which the cutting waste discharged in the coolant with low viscosity sediments easily, and floats near opening of a tub is slight. Since a wire saw is arranged so that it may run the inside of the coolant near opening of a tub in order to cut the cutting section in the condition of having been immersed into the coolant, a wire saw runs the inside of the coolant with little cutting waste, and the coolant with little cutting waste is supplied to the cutting section. The amount of the cutting waste in the coolant supplied to the cutting section can be reduced by supplying the coolant also from opening of a tub and maintaining in the condition of overflowing from opening, especially. Furthermore, the effectiveness which flushes the cutting waste adhering to a wire saw mechanically by the flow of the coolant supplied from opening of a tub is also acquired. As for the amount in which the coolant overflows in 1 minute, it is desirable that it is 50% or more of the volume of a tub. Moreover, many things of the amount of the coolant supplied from opening are more desirable than the amount of the coolant supplied from the pars basilaris ossis occipitalis of a tub.

[0049] Furthermore, since more coolant will be supplied to the perimeter of the cutting section when the corkscrew twist of a tub also makes high the oil level of the coolant which overflows by forming a curtain-like cooling liquid flow (or air current) in opening of a tub, and controlling that the coolant overflows from opening of a tub, the amount of the cutting waste in the coolant can be reduced further. Here, the cooling liquid flow was formed in the shape of a curtain on the side of opening of the tub which intersects the transit direction of a wire saw. As for the discharge pressure for forming a cooling liquid flow, it is desirable that it is within the limits of 20MPa(2kgf) -100MPa (10kgf), and it is still more desirable that it is within the limits of 40MPa(4kgf) -60MPa (6kgf). If a discharge pressure is lower than this range, sufficient effectiveness may not be acquired, when higher than this range, a wire saw may bend, and process tolerance may fall.

[0050] Moreover, it is desirable to carry out the regurgitation of the coolant also to the Maine roller of the pair which is arranged at the both sides of a tub among the Maine rollers formed in order to make it run a wire saw, and regulates the transit location of a wire saw. While controlling the temperature rise of the organic macromolecule layer (for example, polyurethane rubber layer) which has the slot for guiding a wire saw established in the front face of the Maine roller by carrying out the regurgitation of the coolant to these Maine rollers, it can prevent the transit location of a wire saw shifting or separating

from a wire saw fang furrow by flushing the cutting waste (or sludge) which adhered or piled up in the wire saw or the guide rail.

[0051] Moreover, the coolant is reusable by collecting the dirty liquid which consists of a sludge containing the cutting waste of a rare earth alloy generated at the cutting process, and coolant, and classifying the cutting waste of a rare earth alloy using a magnet out of a sludge (for example, cyclically use). As mentioned above, since viscosity is low, the coolant which uses water as a principal component can classify cutting waste easily. Moreover, by classifying the cutting waste of a rare earth alloy, it can carry out so that a damage may not be given to an environment easily [processing / of the coolant / waste fluid]. Furthermore, cutting waste can also be used as a playback raw material of a rare earth alloy. Since it is easy to make low the amount of the carbon contained in the rare earth alloy reproduced from cutting waste since the coolant uses water as a principal component, the raw material used as an ingredient of a rare earth magnet can be obtained. The judgment approach of the cutting waste from a sludge can use the approach which the applicant for this patent indicated to the application for patent No. 224481 [2000 to].

[0052] The cutting process by this invention is applied suitable for cutting of a rare earth sintered alloy with difficult cutting, especially a R-Fe-B system rare earth sintered alloy, as mentioned above. A rare earth magnet is obtained by magnetizing the rare earth alloy cut by the cutting process by this invention. A magnetization process may be performed before a cutting process and may be performed behind. The rare earth sintered magnet manufactured using a R-Fe-B system rare earth sintered alloy is suitably used as an ingredient for voice coil motors used for positioning of the magnetic head. Especially the cutting process by this invention is used suitable for cutting of the R-Fe-B system rare earth sintered magnet (alloy) currently indicated by the U.S. Pat. No. 4,770,723 specification and U.S. Pat. No. 4,792,368 specification by applicants for this patent. furthermore, the hard main phase (iron rich phase) which uses neodymium (Nd), iron (Fe), and boron (B) as a principal component, and consists of a $Nd_2Fe_{14}B$ intermetallic compound of tetragonal structure also in it and Nd -- it is applied suitable for cutting and manufacture of a rare earth sintered magnet (alloy) ("a neodymium magnet (alloy)" is called hereafter.) which have a grain boundary phase with rich stickiness. As a typical example of a neodymium magnet, there are the Sumitomo Special Metals Co., Ltd. make and a trade name NEOMAX.

[0053] if the cutting process by this invention is adopted -- a rare earth alloy -- high degree of accuracy -- and a rare earth magnet (thickness is 0.5mm - 3.0mm) small [for the voice coil motors used for positioning of the magnetic head], for example since it can cut efficiently -- high degree of accuracy -- and it can manufacture efficiently.

[0054] (Operation gestalt) The operation gestalt of the cutting process of the rare earth

alloy by this invention is explained still more concretely hereafter, referring to a drawing. This operation gestalt explains the cutting process of the neodymium magnet sintered compact used for manufacture of an above-mentioned neodymium magnet.
[0055] How to produce a neodymium (Nd-Fe-B) sintered magnet is explained briefly. in addition, the approach of producing the rare earth alloy as a magnet ingredient -- for example, an above-mentioned U.S. Pat. No. 4,770,723 specification -- and it is alike and is indicated by the U.S. Pat. No. 4,792,368 specification at the detail.
[0056] First, after carrying out weighing capacity of the raw material metal to a predetermined component ratio correctly, a raw material metal is dissolved with a RF fusion furnace in a vacuum or an argon gas ambient atmosphere. The dissolved raw material metal is cast to water-cooled mold, and the raw material alloy of a predetermined presentation is formed. This raw material alloy is ground and impalpable powder with a mean particle diameter of about 3-4 micrometers is produced. This impalpable powder is put into metal mold, and press forming is carried out in a field. Press forming is performed after mixing impalpable powder with lubricant if needed at this time. Next, if about 1000-degreeC - abbreviation 1200-degree about C process [sintering] is performed, a neodymium magnet sintered compact is producible. Then, in order to raise magnetic coercive force, aging treatment in about 600-degreeC is performed, and production of a rare earth magnet sintered compact is completed. The size of a sintered compact is 30mmx50mmx50mm.
[0057] Cutting processing of the obtained sintered compact is performed and two or more sheet metal (called a substrate or a wafer) cut from the sintered compact is formed. surface treatment is performed in order to raise long-term dependability, after the sheet metal of the obtained sintered compact is alike, respectively, and receiving, performing finish-machining by polish and preparing a dimension and a configuration. Then, after performing a magnetization process, a neodymium permanent magnet is completed through an inspection process. In addition, a magnetization process may be performed before a cutting process.
[0058] Next, the cutting process by this invention is explained, referring to drawing 3 from drawing 1 .
[0059] Drawing 1 is the outline block diagram showing the wire saw equipment 100 used suitably, in order to perform cutting process of the rare earth alloy of the operation gestalt by this invention.
[0060] Wire saw equipment 100 has three Maine rollers 10a, 10b, and 10c and the reel bobbins 40a and 40b of a pair. The Maine rollers 10b and 10c with which Maine roller 10a prepared in the lower part of the tub 30 which holds the coolant is a driving roller, and is prepared in the both sides of a tub 30 are follower rollers. A wire saw 20 is rolled round by reel bobbin 40b of another side from one reel bobbin 40a, for example, carrying

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out both-way transit. The new wire saw 20 can be supplied to the reel bobbin 40a side, carrying out both-way transit of the wire saw 20 by making rolling-up time amount of 40a of a reel bobbin longer than the rolling-up time amount of reel bobbin 40b of another side at this time. The travel speed of a wire saw 20 is the range of for example, 200 m/min to 1500 m/min, and the rate which supplies a new line is the range of for example, 0 m/min - 5 m/min.

[0061] A wire saw 20 is stretched by for example, 150 trains among the Maine rollers 10a, 10b, and 10c. In order to decide the transit location of a wire saw 20, the organic macromolecule layer (for example, polyurethane rubber layer) which has a slot (for example, a depth of about 0.6mm, un-illustrating) for guiding a wire saw 20 is prepared in the front face of the Maine rollers 10a, 10b, and 10c. Spacing between the trains of a wire saw 20 is decided with the pitch of this guide rail. The pitch of a guide rail is set up according to the thickness of the plate which should be cut down from a work piece.

[0062] Near the reel bobbins 40a and 40b, the traversers 42a and 42b for adjusting a rolling-up location are formed, respectively. Into a path until it results [from the reel bobbins 40a and 40b] in Maine roller 10a, while five guide idlers 44 and one tension roller 46 are formed in the each side and guiding a wire saw 20, the tension is adjusted. Although the tension of a wire saw 20 may be suitably changed according to various conditions (a length of cut, cutting speed, travel speed, etc.), it is set, for example as the range of 20N-40N.

[0063] As the sintered compact work piece 50 produced as mentioned above is the following, it is set in wire saw equipment 100.

[0064] By the adhesives (un-illustrating) of for example, an epoxy system, two or more work pieces 50 fix mutually, are assembled as two or more blocks, are conditions and are fixed to the iron work-piece plate 54 through the carbon base plate 52 in between. Each block and the carbon base plate 52 of the work-piece plate 54 and a work piece 50 have also fixed mutually with adhesives (un-illustrating). After cutting processing of a work piece 50 is completed, the base plate 52 made from carbon receives cutting processing by the wire saw 20 until downward actuation of the work-piece plate 54 stops, and functions as a dummy of protecting the work-piece plate 54.

[0065] With this operation gestalt, each block size is designed so that the size of each block measured along the transit direction of a wire saw 20 may be set to about 100mm. Therefore, the cutting die length by the wire saw 20 is about 200mm here. Although the work piece 50 is divided and arranged to two or more blocks as mentioned above with this operation gestalt, as what magnitude the size in the transit direction of a wire saw 20 should be set changes also with the surface tension and the travel speeds of the coolant. Moreover, the number of work pieces 50 and arrangement which constitute one block also change with the magnitude of each work piece 50. What is necessary is to divide into

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the block of the optimal size suitably and just to arrange a work piece 50 in consideration of these.

[0066] The work piece 50 set as mentioned above descends with a lifting device equipped with a motor 58, and cutting is pushed and carried out to the wire saw 20 it runs. Although the lowering speed of a work piece 50 may change according to various conditions, it is set up within the limits of 20 mm/hr - 50 mm/hr, for example.

[0067] The coolant stored in the coolant tank 60 is fed through piping 63 with the regurgitation pump 62. Piping 63 has branched for the lower piping 64 and the up piping 66 on the way. The bulbs 63b and 63a for adjusting the flow rate of the coolant through which it passes, respectively are formed in the lower piping 64 and the up piping 66. The lower piping 64 is connected to lower nozzle 64a prepared in the pars basilaris ossis occipitalis of the tub 30 for the cutting section being immersed. The up piping 66 is connected to the up nozzles 66a, 66b, and 66c for supplying the coolant from opening of a tub 30, and the up nozzles 66d and 66e prepared in order to cool the Maine rollers 10b and 10c, respectively.

[0068] The coolant is supplied to a tub 30 from the up nozzles 66a, 66b, and 66c and lower nozzle 64a, and at least between cutting processes, as the arrow head F showed in drawing 1 , it is maintained by the condition that the coolant overflows from opening of a tub 30. The coolant which overflowed from the tub 30 is drawn and accumulated in the recovery tank 72 with the pan 70 for recovery with which the tub 30 was formed caudad. The collected coolant is sent to the coolant tank 60 through the piping 76 for circulation with the regurgitation pump 74, as shown in drawing 1 . In the middle of the piping 76 for circulation, the filter 78 is formed and judgment removal of the cutting waste in the collected coolant is carried out. The recovery approach is not restricted to this but the device in which cutting waste is classified using magnetism may be established (for example, refer to application for patent No. 224481 [2000 to]).

[0069] Next, the cutting process by this invention is further explained to a detail, referring to drawing 2 .

[0070] The tub 30 has the auxiliary wall 32 near opening of the side attachment wall which intersects the transit direction of a wire saw 20. This auxiliary wall 32 is formed with the plastic sheet (for example, acrylic board), and it is established so that it may approach in drawing 2 with the transit location of the wire saw at the time of no-load [which was shown with the broken line]. If it descends and a work piece 50 is contacted to a wire saw 20 in order to cut, a wire saw 20 bends, and as the continuous line showed in drawing 2 , the cutting section will be in the condition of having been immersed at the coolant in a tub 30. At this time, a wire saw 20 takes for bending, and a wire saw 20 cuts the auxiliary wall 32, and forms a slit. If cutting by the wire saw 20 will be in a steady state, the amount of deflections is fixed, and a wire saw 20 will cut a work piece 50,

passing through the inside of the slit formed in the auxiliary wall 32. Therefore, the slit formed in the auxiliary wall 32 functions as regulating the transit location of a wire saw 20, and contributes also to the stability of process tolerance.
[0071] The tub 30 has the capacity of about 35 L (liter), and as for the inside of a cutting process, the coolant is supplied by the flow rate of lower nozzle 64a to about 30 L/min, the coolant is supplied by the flow rate of about 90 L/min from the up nozzles 66a, 66b, and 66c, and it is maintained by the condition that the coolant always overflows from opening. Since only considering supplying the coolant to a wire saw 20 a wire saw 29 bends during cutting as shown in drawing 2 , there is not necessarily no need of flooding the coolant, but when cutting the neodymium magnet sintered compact to illustrate, in order to improve eccritic [of cutting waste], it is desirable to adopt the above configurations.
[0072] In order to raise eccritic [of cutting waste], it is effective to reduce the amount of the cutting waste contained in the coolant near the cutting section. In order to acquire eccritic [sufficient], as for the amount in which the coolant overflows in 1 minute, it is desirable that it is 50% or more of the volume of a tub. Furthermore, as for the fresh coolant, supplying mostly from opening is more desirable than the pars basilaris ossis occipitalis of a tub 30. Since it sediments easily, if many coolant is supplied from the pars basilaris ossis occipitalis of a tub 30, since the cutting waste which sedimented will become the cause which floats near the cutting section, the cutting waste discharged in the coolant since the coolant with the low viscosity which uses water as a principal component was used is not desirable.
[0073] Moreover, in order to make [many] the rate that the fresh coolant supplied to a wire saw 20 (that is, cutting slot) from opening occupies, it is more desirable than the wire saw 20 it runs to make [many] the coolant supplied from the upper part. That is, the amount of the cutting waste contained in the coolant supplied to the cutting section can be reduced by supplying the coolant also from opening of a tub 30 and maintaining in the condition of overflowing from opening. Furthermore, the effectiveness which flushes mechanically the cutting waste adhering to a wire saw 20 by the flow of the coolant supplied from opening of a tub 30 is also acquired.
[0074] Moreover, since parts other than the slit formed of the wire saw 20 function as a side attachment wall of a tub 30, the auxiliary wall 32 mentioned above functions as keeping the oil level S of the coolant high. Furthermore, Nozzles 66b and 66c are used for the side which intersects the transit direction of the wire saw 20 of opening of a tub 30, a curtain-like cooling liquid flow is formed in it, and it controls that the coolant overflows from opening of a tub 30. Since more coolant will be supplied to the perimeter of the cutting section when the oil level S of the overflowing coolant is made by this higher than the auxiliary wall 32 of a tub 30, the amount of the cutting waste in the

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coolant can be reduced fur●r. As for the discharge pressur● for forming a cooling liquid flow, it is desirable that it is within the limits of 20MPa(2kgf) -100MPa (10kgf), and it is still more desirable that it is within the limits of 40MPa(4kgf) -60MPa (6kgf). If a discharge pressure is lower than this range, sufficient effectiveness may not be acquired, if higher than this range, blurring may occur in a wire saw 20, consequently process tolerance may fall.

[0075] Moreover, it is desirable to carry out the regurgitation of the coolant also to the Maine rollers 10b and 10c of the pair which is arranged at the both sides of a tub 30 and regulates the transit location of a wire saw 20. By carrying out the regurgitation of the coolant to these Maine rollers 10b and 10c While controlling the temperature rise of the organic macromolecule layer (for example, polyurethane rubber layer) which has the slot for guiding a wire saw 20 established in the front face of the Maine rollers 10b and 10c Since the cutting waste (or sludge) which adhered or piled up in the wire saw 20 or the guide rail can be flushed, while being able to prevent the transit location of a wire saw 20 shifting, or separating from wire saw 20 fang furrow, the effectiveness of improving eccritic is also acquired.

[0076] As an extreme pressure additive mixed by the coolant which uses water as a principal component, a sulfur content compound is desirable. Also in a sulfur content compound, organic acids and these salts, such as alpha of a sulfuration fatty acid, a mercapto fatty acid, a thiocarboxylic acid, and a polysulfide and omega dicarboxylic acid, mercapto alcohol, etc. are desirable.

[0077] As a sulfuration fatty acid, the sulfide of unsaturated fatty acid, such as oleic acid and linolic acid, can be used. The thing of 8-22 has the desirable carbon number of a fatty acid. As a methyl KAPUTO fatty acid, thioglycolic acid and 12-mercapto stearin acid can be used. As a thiocarboxylic acid, thiobenzoic acid and a dithio benzoic acid can be used and a dithio propionic acid and dithio octylic acid can be used as alpha of a polysulfide, and omega dicarboxylic acid. As a base which forms these acids and salts, alkanolamine, alkylamine, ammonia, and an inorganic alkali compound can be used. Mercaptoethanol, mercapto propanol, and mercapto isobutanol can be used as mercapto alcohol.

[0078] As a surfactant added by the coolant which uses water as a principal component, ARUKI roll amide systems, such as polyhydric-alcohol systems, such as polyoxyethylene systems, such as polyoxyethylene alkyl phenyl ether and polyoxyethylene mono-fatty acid ester, and sorbitan mono-fatty acid ester, or fatty-acid diethanolamide, can be used as an anion system as sulfonic acid types, such as sulfate molds, such as fatty-acid derivatives, such as fatty-acid soap and naphthenic-acid soap, or a long-chain alcoholic sulfate, and sulfated oil of animal and vegetable oils, or a petroleum sulfonate, and a non-ion system. Specifically, surface tension and a dynamic friction coefficient can be adjusted within the limits of predetermined by adding chemical solution type JP-0497N

(castrol company make) about 2% of the weight in water.
[0079] Moreover, as synthetic type composition lubricant, a synthetic solution type, a synthetic emulsion type, and a synthetic soluble type can be used, also in it, a synthetic solution type is desirable and the lubricant (#830 and #870 by YUSHIRO CHEMICAL INDUSTRY CO., LTD.) which specifically contains a glycol, alkanolamine, etc., and SHINTAIRO 9954 (castrol company make) can be mentioned. All can adjust surface tension (or dynamic friction coefficient) within suitable limits by adding in water 2 % of the weight to about 10% of the weight.
[0080] Moreover, the corrosion of a rare earth alloy can be prevented by making a rust preventive contain. Here, as for PH, being referred to as 8-11 is desirable. As a rust preventive, a phosphoric acid salt, a borate, molybdate, a tungstate, or a carbonate can be used as amines, such as carboxylate, such as oleate and a benzoate, or triethanolamine, and an inorganic system as an organic system.
[0081] Moreover, nitrides, such as bends triazole, can be used as nonferrous metal anticorrosives, and formaldehyde donators, such as hexa hydro triazine, can be used as antiseptics, for example.
[0082] Moreover, a silicone emulsion can be used as a defoaming agent. By making a defoaming agent contain, foaming of the coolant is lessened, the permeability of the coolant is improved, the cooling effect is heightened, the temperature rise in a wire saw 20 is prevented, and an abnormality rise and anomalous attrition of the temperature of a wire saw 20 stop being able to happen easily.
[0083] The structure of the wire saw 20 suitably used with this operation gestalt is explained referring to drawing 3 . In addition, all over drawing, the lower half is simplified from Chuo Line shown with the alternate long and short dash line of a wire saw 20.
[0084] As a wire saw 20, what fixed the diamond abrasive grain 24 in the resin layer 26 is suitably used for the peripheral face of a core wire (piano wire) 22. Also in it, it is desirable to use phenol resin as resin. The bond strength of phenol resin to the peripheral face of piano wire (hard drawn steel wire) 22 is high, and it excels also in the wettability (permeability) to the coolant mentioned above.
[0085] As an example of the suitable wire saw 20, the diamond abrasive grain whose mean particle diameter is about 45 micrometers is fixed on the periphery of the piano wire 22 whose diameter is about 0.18mm in the phenol resin layer 26, and the wire saw 20 whose outer diameter is about 0.24mm is mentioned to it. Moreover, as for the mean distance between the abrasive grains 26 which adjoin mutually in the transit direction (shaft orientations: direction parallel to the one-point broken line in drawing) of the viewpoint of a cutting efficiency and the discharge effectiveness of cutting waste (sludge) to the wire saw 20, what is within the limits of 200% - 600% of the mean particle

diameter D of an abrasive grain is desirable. Furthermore, as for the average height of the part which the abrasive grain 22 has projected from the front face of the phenol resin layer 26, it is desirable that it is within the limits of 10 micrometers - 40 micrometers. Such a wire saw 20 has eccritic [good] while having a good cutting efficiency, since the space (called a "chip pocket") 28 of moderate magnitude is formed between abrasive grains 22.
[0086] Here, the example of the result of having examined the addition dependency of the extreme pressure additive given to the cutting property of a rare earth alloy about the coolant which contains a sulfuration oleic acid diethanolamine salt as an extreme pressure additive is explained.
[0087] The wire saw equipment 100 shown in drawing 1 was used for cutting. As a wire saw 20, the wire saw by which the industrial diamond abrasive grain with a particle size of 40 micrometers - 60 micrometers was fixed to the core wire with a diameter of 180 micrometers in the phenol resin layer with a thickness of 15 micrometers - 40 micrometers was used. The mean distance between abrasive grains was about 100 micrometers.
[0088] Using NEOMAX-46 by Sumitomo Special Metals Co., Ltd. as a work piece, the die length of a cutting slot was set to 200mm, is in the condition which kept the fall velocity of a work piece constant by 40 mm/h, and measured the tension Fx (the transit direction of a wire saw 20) concerning a wire saw 20, and the reaction force (Fz) over the descent direction using the Xtal piezo-electricity type load cell.
[0089] as cooling water, the YUSHIRO CHEMICAL INDUSTRY CO., LTD. make is synthetic in water (tap water) first -- what did 10 volume % mixing of type composition lubricant #830 was prepared. What added the amount (volume criteria) which shows a sulfuration oleic acid diethanolamine salt in Table 1 was used for this as coolant.
[0090]
[Table 1]

極圧添加剤濃度（ppm）	0	500	1000	2000
切断速度（mm/H）	24.6	29.3	35.7	33.1
切断抵抗：ﾜｲﾔ 1 本あたり				
Fx 張力（N）	0.95	1.13	0.97	0.84
Fz 仕事量（N·mx10^{-3}）	319.8	351.5	353.0	301.9
切断速度換算				
Fx 張力（N）	1.38	1.38	0.97	0.91
Fz 仕事量（N·mx10^{-3}）	464.1	428.3	353.0	325.6

[0091] Fx and Fx are falling by adding 500 ppm or more of extreme pressure additives so that clearly from the result of Table 1. Although the fall inclination of this cutting

resistance was checked to about 20000 ppm, corrosion was looked at by some work pieces when it exceeded 20000 ppm. Moreover, the inclination for the fall of cutting resistance to be mostly saturated in 1000 to 5000 ppm was seen. From these things, it can be said that it is desirable that it is 20000 ppm or less as for the addition of the extreme pressure additive to cooling water, and it is still more desirable that it is [1000 ppm or more] 5000 ppm or less.

[0092]

[Effect of the Invention] According to this invention, the cutting process of the rare earth alloy by the bonded abrasive wire saw which can perform water using the coolant used as a principal component is offered.

[0093] it is high process tolerance and few, when the cutting process of this invention is used -- cut -- since it can come out and a rare earth alloy can be cut, the loss of the ingredient of an expensive rare earth metal alloy is mitigable. Moreover, since the cyclic use of waste water of the coolant is easily realizable, it is environment-friendly and the cost of processing of waste fluid can be reduced. Therefore, the processing cost of a rare earth metal alloy is reduced, and a cutting article, for example, the voice coil motor for the magnetic heads, can be manufactured by the low price.

[Translation done.]

* NOTICES *

TECHNICAL FIELD

[Field of the Invention] Especially this invention relates to the method of cutting a rare earth alloy using the wire saw which made the core wire fix an abrasive grain, and the manufacture approach of the rare earth magnet using it about the cutting process of a rare earth alloy, and the manufacture approach of a rare earth magnet.

[Translation done.]

* NOTICES *

PRIOR ART

[Description of the Prior Art] The rare earth alloy is used as an ingredient of a powerful magnet, for example. The rare earth magnet obtained by magnetizing a rare earth alloy is suitably used as a magnet for voice coil motors used for positioning of the magnetic head of a magnetic recording medium.
[0003] The technique which slices an ingot from the former as an approach of cutting the ingot (a sintered compact being included) of a rare earth alloy, using the slicing blade rotated, for example is adopted. However, according to the approach of cutting with a slicing blade, since the thickness of a cutting cutting edge is comparatively large, a chipping allowance increases, and the yield of a rare earth alloy ingredient is low, and has become the factor which raises the cost of a rare earth alloy product (for example, rare earth magnet).
[0004] There is an approach using the wire saw as a cutting process with few finishing allowances than a slicing blade. For example, JP,11-198020,A is indicating that hard and brittle materials, such as silicon, glass, neodymium, and a ferrite, can be cut using the wire saw (it is called a "bonded abrasive wire".) which fixed superabrasive by the bond layer on the peripheral surface of the core wire of high intensity.

[Translation done.]

* NOTICES *

EFFECT OF THE INVENTION

[Effect of the Invention] According to this invention, the cutting process of the rare earth alloy by the bonded abrasive wire saw which can perform water using the coolant used as a principal component is offered.
[0093] it is high process tolerance and few, when the cutting process of this invention is used -- cut -- since it can come out and a rare earth alloy can be cut, the loss of the ingredient of an expensive rare earth metal alloy is mitigable. Moreover, since the cyclic use of waste water of the coolant is easily realizable, it is environment-friendly and the cost of processing of waste fluid can be reduced. Therefore, the processing cost of a rare earth metal alloy is reduced, and a cutting article, for example, the voice coil motor for the magnetic heads, can be manufactured by the low price.

[Translation done.]

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] If the plate of predetermined thickness is producible from the ingot of a rare earth alloy to several multi-sheet coincidence by few chipping allowances using the above bonded abrasive wire saws, the manufacturing cost of a rare earth magnet will be reduced sharply. However, there is still no report that the rare earth alloy was cut on mass-production level using the bonded abrasive wire saw.
[0006] It is mentioned that the mechanical property of a rare earth alloy and the rare earth alloy (a "rare earth sintered alloy" is called hereafter.) especially manufactured by the sintering process differs from silicon etc. greatly as this main cause from the result which the artificer examined variously. Since it has the hard main phase (R2Fe14 B phase) which causes brittleness--mainly destruction, and the grain boundary phase (R rich phase) which causes ductility-destruction, specifically, unlike the hard and brittle material represented by silicon, a rare earth sintered alloy is hard to be cut. That is, compared with the case where hard and brittle materials, such as silicon, are cut, cutting force is high, consequently calorific value also has it. [much] Moreover, the specific gravity of a rare earth alloy is large compared with ingredients, such as about 7.5 and silicon, and the cutting waste (sludge) generated by cutting is hard to be discharged from the cutting section.
[0007] Therefore, in order to cut a rare earth alloy efficiently with high process tolerance, while fully reducing cutting force, heat is efficiently radiated in the heat generated at the time of cutting, namely, it is necessary to cool the cutting section efficiently. Moreover, it is necessary to discharge efficiently the cutting waste generated by cutting.
[0008] While falling cutting force by fully supplying the coolant (it also being called "cutting fluid".) excellent in lubricity to the cutting section of a rare earth alloy, the heat generated at the time of cutting can be radiated efficiently. If the wire saw is soaked in sufficient quantity of the coolant using the oily coolant as a result of the experiment by the artificer, the coolant can fully be supplied to the narrow cutting section by the wire

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saw it runs.

[0009] However, in order to process waste fluid so that environmental destruction may not be caused, it is difficult for the oily coolant that cost starts and to classify the cutting waste in waste fluid, and there is a problem that reuse of waste fluid or cutting waste is difficult. Moreover, in case cutting waste is reused, the carbon content in a raw material increases, and in order to reduce magnetic properties, there is also a problem of not being desirable. If these things are taken into consideration, as coolant, water (or water-soluble coolant) is desirable, but if water is used as coolant, since amount sufficient since viscosity (1.0mm2/s) is low for the wire saw it runs cannot be made to adhere, even if water wets a wire saw with water, it cannot supply the water of sufficient amount for the cutting section.

[0010] By making it run a wire saw in the coolant overflowed from the tub of the coolant, JP,11-198020,A is indicating that the coolant can be made to adhere to a wire saw certainly, when making it run a bonded abrasive wire saw at high speed (for example, 2000 m/min). However, according to the experiment of this invention person, even if it cuts a rare earth alloy, making it run a wire saw (for example, indicated by JP,11-198020,A) in the water currently overflowed, omission of an abrasive grain, and in being severe, an open circuit of a wire saw occurs. The travel speed of a wire saw generated this fault also for example, in 800 m/min extent. Even if it adopts the above-mentioned approach, this has high cutting force and is considered because water is not fully supplied to the cutting section.

[0011] This invention is made in view of these many points, and the main purpose is in offering the cutting process of the rare earth alloy by the bonded abrasive wire saw which can be performed using the coolant which uses water as a principal component. Moreover, other purposes of this invention are to offer the voice coil motor equipped with the manufacture approach of a rare earth magnet of having used the cutting process of the above-mentioned rare earth alloy, and the rare earth magnet concerned.

[Translation done.]

MEANS

[Means for Solving the Problem] It is in the condition to which the cutting process of the rare earth alloy by this invention is the cutting process of the rare earth alloy using the wire saw which made the core wire fix an abrasive grain, and said rare earth alloy was immersed [water] in the coolant used as a principal component in the part cut by said wire saw. By making it run said wire saw, the process which cuts said rare earth alloy is included, it is characterized by said coolant containing 500 ppm or more an extreme pressure additive 20000 ppm or less on volume criteria, and the above-mentioned purpose is attained by that.
[0013] As for said extreme pressure additive, it is desirable that it is a sulfur content compound.
[0014] As for the surface tension in 25-degreeC of said coolant, it is desirable that it is within the limits of 25 mN/m - 60 mN/m.
[0015] As for said coolant, it is desirable that the water of the weight within the limits of 10 times to 50 times of the weight of water-soluble synthetic lubricant and said synthetic lubricant is included.
[0016] Or said coolant may also contain the water of the weight within the limits of 10 times to 50 times of the weight of a surfactant and a surfactant.
[0017] Said coolant may also contain a defoaming agent. As for said coolant, it is desirable that PHs are 8-11. Moreover, said coolant may also contain a rusr-proofer.
[0018] As for said abrasive grain, it is desirable to have fixed by the phenol resin layer formed in the peripheral face of said core wire.
[0019] As for the average height of the part which the mean distance between said abrasive grains which adjoin mutually has within the limits of 200% - 600% of the mean particle diameter of said abrasive grain, and said abrasive grain has projected from the front face of said phenol resin layer in the transit direction of said wire saw, it is desirable that it is within the limits of 10 micrometers - 40 micrometers.

[0020] As for the mean particle diameter D of said abrasive grain, it is desirable to satisfy 20 micrometer<=D <=60micrometer relation.
[0021] In said cutting process, it is immersed in said coolant by which the part in which said rare earth alloy is cut by said wire saw was held in the tub, and being maintained by the condition of overflowing from said opening is desirable [the coolant] by being supplied from opening of said tub while said coolant is supplied in said tub from the pars basilaris ossis occipitalis of said tub.
[0022] As for the amount in which said coolant overflows in 1 minute, in said cutting process, it is desirable that it is 50% or more of the volume of said tub.
[0023] In said cutting process, many things of the amount of said coolant supplied from said opening are more desirable than the amount of said coolant supplied from said pars basilaris ossis occipitalis.
[0024] In said cutting process, it is desirable by forming curtain-like an air current or a cooling liquid flow in said opening of said tub to control that said coolant overflows from said opening of said tub.
[0025] Said rare earth alloy may be a R-Fe-B system rare earth sintered alloy, and may be a Nd-Fe-B system rare earth sintered alloy. In addition, R is the rare earth elements containing Y.
[0026] The manufacture approach of the rare earth magnet of this invention includes the process which produces the sintered compact of a rare earth magnet from rare earth alloy powder, and the process which separates two or more rare earth magnets from said sintered compact using the cutting process of one of the above-mentioned rare earth alloys, and the above-mentioned purpose is attained by that.
[0027] The voice coil motor by this invention is equipped with the rare earth magnet produced by the manufacture approach of the above-mentioned rare earth magnet. The thickness of said rare earth magnet may be in the range which is 0.5mm - 3.0mm.
[0028]
[Embodiment of the Invention] Below, the cutting process of the rare earth alloy of the operation gestalt by this invention and the manufacture approach of a rare earth magnet are explained.
[0029] The cutting process of the rare earth alloy by this invention is the cutting process of the rare earth alloy using the wire saw which made the core wire (typically piano wire) fix an abrasive grain (typically diamond abrasive grain), while a rare earth alloy supplies the coolant which uses water as a principal component to the part cut by the wire saw, by making it run a wire saw, the process which cuts a rare earth alloy is included and the coolant contains 500 ppm or more an extreme pressure additive 20000 ppm or less on volume criteria. As for an extreme pressure additive, it is desirable that it is a sulfur content compound. In addition, in this specification, "the coolant which uses water as a

principal component" means the coolant whose 70% of the weight or more of the whole is water.
[0030] With the frictional heat generated at the time of cutting, an extreme pressure additive reacts chemically with the metallic element (mainly iron) which constitutes a rare earth alloy, and forms metallic compounds. Therefore, although it is hard to cut a rare earth alloy, the ductility is reduced by the extreme pressure additive, and cutting force becomes low. Therefore, even if it uses the coolant of a drainage system with low lubricity compared with the oily coolant, it becomes possible to cut a rare earth alloy efficiently.
[0031] It is desirable to use the compound (called a sulfur system extreme pressure additive) containing sulfur (S) as an extreme pressure additive. A sulfur system extreme pressure additive reacts with the iron contained in a rare earth alloy, forms an iron sulfide, and is excellent in the effectiveness of embrittling the contact surface. In addition, for example, the phosphorus system extreme pressure additive and phosphorus-sulfur system extreme pressure additive other than a sulfur system extreme pressure additive can also be used.
[0032] Although especially the sulfur content compound suitably used as an extreme pressure additive added by the coolant of this invention is not limited, what has the high compatibility (solubility or homogeneity dispersibility) over water is desirable, and it is desirable that they are an acid, a salt, or lower alcohol. For example, organic acids and these salts, such as alpha of a sulfuration fatty acid, a mercapto fatty acid, a thiocarboxylic acid, and a polysulfide and omega dicarboxylic acid, mercapto alcohol, etc. can be mentioned. Especially, alpha of a sulfuration fatty acid and a polysulfide, omega dicarboxylic acid, and these salts are desirable. A sulfur content compound may use one sort independently, and may use it combining two or more sorts.
[0033] As for the addition to the whole coolant of an extreme pressure additive, it is desirable that it is 500 ppm or more 20000 ppm or less on volume criteria, and it is still more desirable that it is [1000 ppm or more] 5000 ppm or less. When the effectiveness of an extreme pressure additive may not fully be demonstrated if it is less than 500 ppm, and it exceeds 20000 ppm, it may react beyond a rare earth alloy and the need, and dependability (corrosion resistance) may be spoiled.
[0034] Furthermore, as for the surface tension in 25-degreeC of the coolant, it is desirable that it is within the limits of 25 mN/m - 60 mN/m. As coolant, the dynamic friction coefficient in 25-degreeC to a rare earth alloy may use the thing of 0.1-0.3.
[0035] A wire saw can be efficiently cooled by performing the process which cuts a rare earth alloy using a bonded abrasive wire saw in the condition of having been immersed in the coolant which has the surface tension in 25-degreeC within the limits of about 25 mN/m - about 60 mN/m (about 25 dyn/cm - about 60 dyn/cm) in the cutting section.

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Since the wettability (or concordance) to a rare earth alloy and/or a wire saw is excellent compared with water, the coolant which has the above-mentioned surface tension within the limits is the cutting section (part by which a rare earth alloy and a wire saw contact mutually, and a rare earth alloy is cut.). It is also called a cutting slot. It thinks for the coolant to permeate efficiently. Of course, since the specific heat is large compared with the oily coolant (for example, mineral oil), the coolant which uses water as a principal component has high cooling effectiveness.
[0036] The coolant suitably used in the cutting process of the rare earth alloy of this invention can also be sorted out with the dynamic friction coefficient to the above-mentioned rare earth alloy, and the coolant which has the above-mentioned dynamic friction coefficient in 25-degreeC in about 0.1 - about 0.3 within the limits can demonstrate an operation and effectiveness equivalent to the coolant which has the above-mentioned surface tension within the limits. A dynamic friction coefficient is considered to be the lubricative index which the coolant gives to the cutting section to surface tension being considered to be the index which shows the permeability of the coolant to the cutting section. In addition, it is known that a qualitative correlation is between surface tension and a dynamic friction coefficient.
[0037] The surface tension of the coolant is measured using the DEYUNUI surface tension balance known well. Moreover, dynamic coefficient of friction of the coolant to a rare earth alloy is measured in Japan using a Masuda style "a walk type friction tester" currently used abundantly as a fundamental testing machine. In this specification, each adopts the value in 25-degreeC as a value by which the coolant is characterized.
[0038] In addition, the dynamic friction coefficient shown in the following examples is the value calculated with the walk type friction tester using the iron ball. Since there are most iron contents in a component element, the R-Fe-B system rare earth alloy (for example, alloy which makes a Nd2Fe14B intermetallic compound the main phase) illustrated in the example is good approximation, and the dynamic friction coefficient of the coolant for which it asked using the iron ball can be used for it as a dynamic friction coefficient to a rare earth alloy. The presentation and the manufacture approach of a rare earth alloy which are suitably used as a rare earth magnet are indicated by U.S. Pat. No. 4,770,723 and U.S. Pat. No. 4,792,368.
[0039] In addition, although the coolant suitably used with the cutting process of this invention was specified using the surface tension or the dynamic friction coefficient of 25-degreeC, the temperature of the coolant at the time of actually using it is not restricted to 25-degreeC. However, in order to acquire the effectiveness of this invention, it is desirable to use the coolant by which temperature control was carried out within the limits of 15-degreeC-35-degreeC, it is still more desirable that it is within the limits of 20-degreeC-30-degreeC, and it is still more desirable that it is within the limits of 20-

degreeC-25-degreeC. Since it depends for the surface tension and the dynamic friction coefficient of the coolant on temperature as known well, if it separates not much from the temperature requirement of the above [the temperature of the actually used coolant], the surface tension and the dynamic friction coefficient of the coolant will be in the condition of having resembled well the condition of having separated from the above-mentioned numerical range, respectively, and cooling effectiveness will fall.
[0040] Since the abnormality rise of the temperature of a wire saw can be controlled by using the coolant which has the surface tension (or dynamic friction coefficient) of the above-mentioned range, abnormality degraining of an abrasive grain and an open circuit of a wire saw can be controlled and prevented still more efficiently. Consequently, while the fall of process tolerance is prevented, since it becomes possible to use a wire saw for a period longer than before, a manufacturing cost can be reduced.
[0041] The coolant which has the surface tension (or dynamic friction coefficient) of the above-mentioned range is prepared by adding in water a surface active agent and the so-called synthetic lubricant called "synthetic [synthetic (Synthetic)]." By adjusting a class and an addition, predetermined surface tension and a predetermined dynamic friction coefficient can be obtained. Moreover, since viscosity is comparatively low when the coolant which uses water as a principal component is used, it is possible to classify the cutting waste of a rare earth alloy from the sludge generated by cutting easily using a magnet, and the coolant can be reused. Moreover, it can prevent having a bad influence on natural environment by abandonment processing of the coolant. Moreover, the amount of the carbon contained in a sludge can be reduced and the magnetic properties of the magnet which uses as a raw material the cutting waste collected from the sludge can be improved.
[0042] When it cuts making it run a wire saw at high speed, the coolant may foam and cooling effectiveness may fall. By using the coolant containing a defoaming agent, decline in the cooling effectiveness by foaming of the coolant can be controlled. Furthermore, the corrosion of a rare earth alloy can be controlled by using the coolant which has PH within the limits of 8-11. Moreover, oxidation of a rare earth alloy can be controlled by using the coolant containing a rusr-proofer. What is necessary is just to adjust these suitably in consideration of a class, cutting conditions, etc. of a rare earth alloy.
[0043] As a wire saw, what fixed the diamond system abrasive grain by resin is used suitably. That is, the wire saw which used resin and fixed the diamond system abrasive grain to the peripheral face of a core wire (typically piano wire) can be used suitably. Also in it, it is desirable to use phenol resin as resin. The bond strength of phenol resin to the peripheral face of piano wire (hard drawn steel wire) is high, and it excels also in the wettability (permeability) to the coolant mentioned later. Moreover, it is cheaper than the

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wire saw manufactured using an electrodeposition process, and the cost concerning cutting of a rare earth alloy can be reduced. Although the fixing force of an abrasive grain is weak compared with the wire saw produced by the electrodeposition process (an abrasive grain is fixed for example, with nickel plating etc.), since peeling of an abrasive grain etc. can be lessened by using the coolant adjusted to the range which mentioned the dynamic friction coefficient above, it becomes possible to cut the rare earth alloy which is hard to cut.

[0044] In addition, the core wire of a wire saw may not be restricted to piano wire, but may be formed from what bundled high intensity fiber, such as a thing formed from refractory metals, such as alloys, such as nickel-Cr and Fe-nickel, W, and Mo, or nylon fiber. Moreover, the ingredient of an abrasive grain may not be limited to a diamond, but may be SiC, B, C, CBN (Cubic Boron Nitride), etc.

[0045] In order to acquire the advantage that it cuts and there is little **, the outer diameter of a wire saw has 0.3 desirablemm or less, and it is still more desirable that it is 0.25mm or less. In order that it may be set up and the lower limit of the outer diameter of a wire saw may fix the abrasive grain of predetermined magnitude by sufficient reinforcement so that sufficient reinforcement may be obtained, a core wire with a diameter of about 0.12-0.20mm is used. As for the mean particle diameter D of an abrasive grain, it is desirable to satisfy 20 micrometer<=D <=60micrometer relation from a viewpoint of a cutting efficiency, and it is desirable to satisfy especially the relation which is 40 micrometer<=D <=60micrometer. Moreover, as for the mean distance between the abrasive grains which adjoin mutually in the transit direction of the viewpoint of a cutting efficiency and the discharge effectiveness of cutting waste (sludge) to a wire saw, it is desirable that it is within the limits of 200% - 600% of the mean particle diameter D of an abrasive grain, and, as for the average height of the part which the abrasive grain has projected from the front face of a phenol resin layer, it is desirable that it is within the limits of 10 micrometers - 40 micrometers. this wire saw may be supplied by the manufacturer (for example, incorporated company ally DOMATE -- real) of a general wire saw if the above-mentioned specification is specified.

[0046] Since a good cutting efficiency can be realized and it excels also in eccritic [of cutting waste] when such a wire saw is used, it can cut also at a comparatively high travel speed (for example, 1000 m/min). Moreover, since it is efficiently cooled by the above-mentioned coolant, with good process tolerance, it can continue at a long period of time, and a rare earth alloy can be cut to stability.

[0047] The coolant which uses as a principal component the water used for the cutting process of this invention is one with low (kinematic viscosity is about 1mm2/s) viscosity, and eccritic [of cutting waste] is lower than the oily coolant (kinematic viscosity is generally more than 5mm2/s). Then, it is maintained by the condition of having been

immersed in the coolant by which the cutting section was held in the tub in the cutting process in order to raise eccritic [of cutting waste], and being maintained by the condition of overflowing from opening of a tub is desirable [the coolant] by being supplied from opening of a tub while the coolant is supplied in a tub from the pars basilaris ossis occipitalis of a tub.

[0048] The cutting waste which the cutting waste discharged in the coolant with low viscosity sediments easily, and floats near opening of a tub is slight. Since a wire saw is arranged so that it may run the inside of the coolant near opening of a tub in order to cut the cutting section in the condition of having been immersed into the coolant, a wire saw runs the inside of the coolant with little cutting waste, and the coolant with little cutting waste is supplied to the cutting section. The amount of the cutting waste in the coolant supplied to the cutting section can be reduced by supplying the coolant also from opening of a tub and maintaining in the condition of overflowing from opening, especially. Furthermore, the effectiveness which flushes the cutting waste adhering to a wire saw mechanically by the flow of the coolant supplied from opening of a tub is also acquired. As for the amount in which the coolant overflows in 1 minute, it is desirable that it is 50% or more of the volume of a tub. Moreover, many things of the amount of the coolant supplied from opening are more desirable than the amount of the coolant supplied from the pars basilaris ossis occipitalis of a tub.

[0049] Furthermore, since more coolant will be supplied to the perimeter of the cutting section when the corkscrew twist of a tub also makes high the oil level of the coolant which overflows by forming a curtain-like cooling liquid flow (or air current) in opening of a tub, and controlling that the coolant overflows from opening of a tub, the amount of the cutting waste in the coolant can be reduced further. Here, the cooling liquid flow was formed in the shape of a curtain on the side of opening of the tub which intersects the transit direction of a wire saw. As for the discharge pressure for forming a cooling liquid flow, it is desirable that it is within the limits of 20MPa(2kgf) -100MPa (10kgf), and it is still more desirable that it is within the limits of 40MPa(4kgf) -60MPa (6kgf). If a discharge pressure is lower than this range, sufficient effectiveness may not be acquired, when higher than this range, a wire saw may bend, and process tolerance may fall.

[0050] Moreover, it is desirable to carry out the regurgitation of the coolant also to the Maine roller of the pair which is arranged at the both sides of a tub among the Maine rollers formed in order to make it run a wire saw, and regulates the transit location of a wire saw. While controlling the temperature rise of the organic macromolecule layer (for example, polyurethane rubber layer) which has the slot for guiding a wire saw established in the front face of the Maine roller by carrying out the regurgitation of the coolant to these Maine rollers, it can prevent the transit location of a wire saw shifting or separating from a wire saw fang furrow by flushing the cutting waste (or sludge) which adhered or

piled up in the wire saw of the guide rail.
[0051] Moreover, the coolant is reusable by collecting the dirty liquid which consists of a sludge containing the cutting waste of a rare earth alloy generated at the cutting process, and coolant, and classifying the cutting waste of a rare earth alloy using a magnet out of a sludge (for example, cyclically use). As mentioned above, since viscosity is low, the coolant which uses water as a principal component can classify cutting waste easily. Moreover, by classifying the cutting waste of a rare earth alloy, it can carry out so that a damage may not be given to an environment easily [processing / of the coolant / waste fluid]. Furthermore, cutting waste can also be used as a playback raw material of a rare earth alloy. Since it is easy to make low the amount of the carbon contained in the rare earth alloy reproduced from cutting waste since the coolant uses water as a principal component, the raw material used as an ingredient of a rare earth magnet can be obtained. The judgment approach of the cutting waste from a sludge can use the approach which the applicant for this patent indicated to the application for patent No. 224481 [2000 to].

[0052] The cutting process by this invention is applied suitable for cutting of a rare earth sintered alloy with difficult cutting, especially a R-Fe-B system rare earth sintered alloy, as mentioned above. A rare earth magnet is obtained by magnetizing the rare earth alloy cut by the cutting process by this invention. A magnetization process may be performed before a cutting process and may be performed behind. The rare earth sintered magnet manufactured using a R-Fe-B system rare earth sintered alloy is suitably used as an ingredient for voice coil motors used for positioning of the magnetic head. Especially the cutting process by this invention is used suitable for cutting of the R-Fe-B system rare earth sintered magnet (alloy) currently indicated by the U.S. Pat. No. 4,770,723 specification and U.S. Pat. No. 4,792,368 specification by applicants for this patent. furthermore, the hard main phase (iron rich phase) which uses neodymium (Nd), iron (Fe), and boron (B) as a principal component, and consists of a $Nd_2Fe_{14}B$ intermetallic compound of tetragonal structure also in it and Nd -- it is applied suitable for cutting and manufacture of a rare earth sintered magnet (alloy) ("a neodymium magnet (alloy)" is called hereafter.) which have a grain boundary phase with rich stickiness. As a typical example of a neodymium magnet, there are the Sumitomo Special Metals Co., Ltd. make and a trade name NEOMAX.
[0053] if the cutting process by this invention is adopted -- a rare earth alloy -- high degree of accuracy -- and a rare earth magnet (thickness is 0.5mm - 3.0mm) small [for the voice coil motors used for positioning of the magnetic head], for example since it can cut efficiently -- high degree of accuracy -- and it can manufacture efficiently.
[0054] (Operation gestalt) The operation gestalt of the cutting process of the rare earth alloy by this invention is explained still more concretely hereafter, referring to a drawing.

This operation gestalt explains the cutting process of the neodymium magnet sintered compact used for manufacture of an above-mentioned neodymium magnet.
[0055] How to produce a neodymium (Nd-Fe-B) sintered magnet is explained briefly. in addition, the approach of producing the rare earth alloy as a magnet ingredient -- for example, an above-mentioned U.S. Pat. No. 4,770,723 specification -- and it is alike and is indicated by the U.S. Pat. No. 4,792,368 specification at the detail.
[0056] First, after carrying out weighing capacity of the raw material metal to a predetermined component ratio correctly, a raw material metal is dissolved with a RF fusion furnace in a vacuum or an argon gas ambient atmosphere. The dissolved raw material metal is cast to water-cooled mold, and the raw material alloy of a predetermined presentation is formed. This raw material alloy is ground and impalpable powder with a mean particle diameter of about 3-4 micrometers is produced. This impalpable powder is put into metal mold, and press forming is carried out in a field. Press forming is performed after mixing impalpable powder with lubricant if needed at this time. Next, if about 1000-degreeC - abbreviation 1200-degree about C process [sintering] is performed, a neodymium magnet sintered compact is producible. Then, in order to raise magnetic coercive force, aging treatment in about 600-degreeC is performed, and production of a rare earth magnet sintered compact is completed. The size of a sintered compact is 30mmx50mmx50mm.
[0057] Cutting processing of the obtained sintered compact is performed and two or more sheet metal (called a substrate or a wafer) cut from the sintered compact is formed. surface treatment is performed in order to raise long-term dependability, after the sheet metal of the obtained sintered compact is alike, respectively, and receiving, performing finish-machining by polish and preparing a dimension and a configuration. Then, after performing a magnetization process, a neodymium permanent magnet is completed through an inspection process. In addition, a magnetization process may be performed before a cutting process.
[0058] Next, the cutting process by this invention is explained, referring to drawing 3 from drawing 1 .
[0059] Drawing 1 is the outline block diagram showing the wire saw equipment 100 used suitably, in order to perform cutting process of the rare earth alloy of the operation gestalt by this invention.
[0060] Wire saw equipment 100 has three Maine rollers 10a, 10b, and 10c and the reel bobbins 40a and 40b of a pair. The Maine rollers 10b and 10c with which Maine roller 10a prepared in the lower part of the tub 30 which holds the coolant is a driving roller, and is prepared in the both sides of a tub 30 are follower rollers. A wire saw 20 is rolled round by reel bobbin 40b of another side from one reel bobbin 40a, for example, carrying out both-way transit. The new wire saw 20 can be supplied to the reel bobbin 40a side,

carrying out both-way transit of the wire saw 20 by making rolling-up time amount of 40a of a reel bobbin longer than the rolling-up time amount of reel bobbin 40b of another side at this time. The travel speed of a wire saw 20 is the range of for example, 200 m/min to 1500 m/min, and the rate which supplies a new line is the range of for example, 0 m/min - 5 m/min.

[0061] A wire saw 20 is stretched by for example, 150 trains among the Maine rollers 10a, 10b, and 10c. In order to decide the transit location of a wire saw 20, the organic macromolecule layer (for example, polyurethane rubber layer) which has a slot (for example, a depth of about 0.6mm, un-illustrating) for guiding a wire saw 20 is prepared in the front face of the Maine rollers 10a, 10b, and 10c. Spacing between the trains of a wire saw 20 is decided with the pitch of this guide rail. The pitch of a guide rail is set up according to the thickness of the plate which should be cut down from a work piece.

[0062] Near the reel bobbins 40a and 40b, the traversers 42a and 42b for adjusting a rolling-up location are formed, respectively. Into a path until it results [from the reel bobbins 40a and 40b] in Maine roller 10a, while five guide idlers 44 and one tension roller 46 are formed in the each side and guiding a wire saw 20, the tension is adjusted. Although the tension of a wire saw 20 may be suitably changed according to various conditions (a length of cut, cutting speed, travel speed, etc.), it is set, for example as the range of 20N-40N.

[0063] As the sintered compact work piece 50 produced as mentioned above is the following, it is set in wire saw equipment 100.

[0064] By the adhesives (un-illustrating) of for example, an epoxy system, two or more work pieces 50 fix mutually, are assembled as two or more blocks, are conditions and are fixed to the iron work-piece plate 54 through the carbon base plate 52 in between. Each block and the carbon base plate 52 of the work-piece plate 54 and a work piece 50 have also fixed mutually with adhesives (un-illustrating). After cutting processing of a work piece 50 is completed, the base plate 52 made from carbon receives cutting processing by the wire saw 20 until downward actuation of the work-piece plate 54 stops, and functions as a dummy of protecting the work-piece plate 54.

[0065] With this operation gestalt, each block size is designed so that the size of each block measured along the transit direction of a wire saw 20 may be set to about 100mm. Therefore, the cutting die length by the wire saw 20 is about 200mm here. Although the work piece 50 is divided and arranged to two or more blocks as mentioned above with this operation gestalt, as what magnitude the size in the transit direction of a wire saw 20 should be set changes also with the surface tension and the travel speeds of the coolant. Moreover, the number of work pieces 50 and arrangement which constitute one block also change with the magnitude of each work piece 50. What is necessary is to divide into the block of the optimal size suitably and just to arrange a work piece 50 in consideration

of these.
[0066] The work piece 50 set as mentioned above descends with a lifting device equipped with a motor 58, and cutting is pushed and carried out to the wire saw 20 it runs. Although the lowering speed of a work piece 50 may change according to various conditions, it is set up within the limits of 20 mm/hr - 50 mm/hr, for example.
[0067] The coolant stored in the coolant tank 60 is fed through piping 63 with the regurgitation pump 62. Piping 63 has branched for the lower piping 64 and the up piping 66 on the way. The bulbs 63b and 63a for adjusting the flow rate of the coolant through which it passes, respectively are formed in the lower piping 64 and the up piping 66. The lower piping 64 is connected to lower nozzle 64a prepared in the pars basilaris ossis occipitalis of the tub 30 for the cutting section being immersed. The up piping 66 is connected to the up nozzles 66a, 66b, and 66c for supplying the coolant from opening of a tub 30, and the up nozzles 66d and 66e prepared in order to cool the Maine rollers 10b and 10c, respectively.
[0068] The coolant is supplied to a tub 30 from the up nozzles 66a, 66b, and 66c and lower nozzle 64a, and at least between cutting processes, as the arrow head F showed in drawing 1 , it is maintained by the condition that the coolant overflows from opening of a tub 30. The coolant which overflowed from the tub 30 is drawn and accumulated in the recovery tank 72 with the pan 70 for recovery with which the tub 30 was formed caudad. The collected coolant is sent to the coolant tank 60 through the piping 76 for circulation with the regurgitation pump 74, as shown in drawing 1 . In the middle of the piping 76 for circulation, the filter 78 is formed and judgment removal of the cutting waste in the collected coolant is carried out. The recovery approach is not restricted to this but the device in which cutting waste is classified using magnetism may be established (for example, refer to application for patent No. 224481 [2000 to]).
[0069] Next, the cutting process by this invention is further explained to a detail, referring to drawing 2 .
[0070] The tub 30 has the auxiliary wall 32 near opening of the side attachment wall which intersects the transit direction of a wire saw 20. This auxiliary wall 32 is formed with the plastic sheet (for example, acrylic board), and it is established so that it may approach in drawing 2 with the transit location of the wire saw at the time of no-load [which was shown with the broken line]. If it descends and a work piece 50 is contacted to a wire saw 20 in order to cut, a wire saw 20 bends, and as the continuous line showed in drawing 2 , the cutting section will be in the condition of having been immersed at the coolant in a tub 30. At this time, a wire saw 20 takes for bending, and a wire saw 20 cuts the auxiliary wall 32, and forms a slit. If cutting by the wire saw 20 will be in a steady state, the amount of deflections is fixed, and a wire saw 20 will cut a work piece 50, passing through the inside of the slit formed in the auxiliary wall 32. Therefore, the slit

formed in the auxiliary wall 32 functions as regulating the transit location of a wire saw 20, and contributes also to the stability of process tolerance.
[0071] The tub 30 has the capacity of about 35 L (liter), and as for the inside of a cutting process, the coolant is supplied by the flow rate of lower nozzle 64a to about 30 L/min, the coolant is supplied by the flow rate of about 90 L/min from the up nozzles 66a, 66b, and 66c, and it is maintained by the condition that the coolant always overflows from opening. Since only considering supplying the coolant to a wire saw 20 a wire saw 29 bends during cutting as shown in drawing 2 , there is not necessarily no need of flooding the coolant, but when cutting the neodymium magnet sintered compact to illustrate, in order to improve eccritic [of cutting waste], it is desirable to adopt the above configurations.
[0072] In order to raise eccritic [of cutting waste], it is effective to reduce the amount of the cutting waste contained in the coolant near the cutting section. In order to acquire eccritic [sufficient], as for the amount in which the coolant overflows in 1 minute, it is desirable that it is 50% or more of the volume of a tub. Furthermore, as for the fresh coolant, supplying mostly from opening is more desirable than the pars basilaris ossis occipitalis of a tub 30. Since it sediments easily, if many coolant is supplied from the pars basilaris ossis occipitalis of a tub 30, since the cutting waste which sedimented will become the cause which floats near the cutting section, the cutting waste discharged in the coolant since the coolant with the low viscosity which uses water as a principal component was used is not desirable.
[0073] Moreover, in order to make [many] the rate that the fresh coolant supplied to a wire saw 20 (that is, cutting slot) from opening occupies, it is more desirable than the wire saw 20 it runs to make [many] the coolant supplied from the upper part. That is, the amount of the cutting waste contained in the coolant supplied to the cutting section can be reduced by supplying the coolant also from opening of a tub 30 and maintaining in the condition of overflowing from opening. Furthermore, the effectiveness which flushes mechanically the cutting waste adhering to a wire saw 20 by the flow of the coolant supplied from opening of a tub 30 is also acquired.
[0074] Moreover, since parts other than the slit formed of the wire saw 20 function as a side attachment wall of a tub 30, the auxiliary wall 32 mentioned above functions as keeping the oil level S of the coolant high. Furthermore, Nozzles 66b and 66c are used for the side which intersects the transit direction of the wire saw 20 of opening of a tub 30, a curtain-like cooling liquid flow is formed in it, and it controls that the coolant overflows from opening of a tub 30. Since more coolant will be supplied to the perimeter of the cutting section when the oil level S of the overflowing coolant is made by this higher than the auxiliary wall 32 of a tub 30, the amount of the cutting waste in the coolant can be reduced further. As for the discharge pressure for forming a cooling liquid

flow, it is desirable that it is within the limits of 20MPa(2kgf) -100MPa (10kgf), and it is still more desirable that it is within the limits of 40MPa(4kgf) -60MPa (6kgf). If a discharge pressure is lower than this range, sufficient effectiveness may not be acquired, if higher than this range, blurring may occur in a wire saw 20, consequently process tolerance may fall.

[0075] Moreover, it is desirable to carry out the regurgitation of the coolant also to the Maine rollers 10b and 10c of the pair which is arranged at the both sides of a tub 30 and regulates the transit location of a wire saw 20. By carrying out the regurgitation of the coolant to these Maine rollers 10b and 10c While controlling the temperature rise of the organic macromolecule layer (for example, polyurethane rubber layer) which has the slot for guiding a wire saw 20 established in the front face of the Maine rollers 10b and 10c Since the cutting waste (or sludge) which adhered or piled up in the wire saw 20 or the guide rail can be flushed, while being able to prevent the transit location of a wire saw 20 shifting, or separating from wire saw 20 fang furrow, the effectiveness of improving eccritic is also acquired.

[0076] As an extreme pressure additive mixed by the coolant which uses water as a principal component, a sulfur content compound is desirable. Also in a sulfur content compound, organic acids and these salts, such as alpha of a sulfuration fatty acid, a mercapto fatty acid, a thiocarboxylic acid, and a polysulfide and omega dicarboxylic acid, mercapto alcohol, etc. are desirable.

[0077] As a sulfuration fatty acid, the sulfide of unsaturated fatty acid, such as oleic acid and linolic acid, can be used. The thing of 8-22 has the desirable carbon number of a fatty acid. As a methyl KAPUTO fatty acid, thioglycolic acid and 12-mercapto stearin acid can be used. As a thiocarboxylic acid, thiobenzoic acid and a dithio benzoic acid can be used and a dithio propionic acid and dithio octylic acid can be used as alpha of a polysulfide, and omega dicarboxylic acid. As a base which forms these acids and salts, alkanolamine, alkylamine, ammonia, and an inorganic alkali compound can be used. Mercaptoethanol, mercapto propanol, and mercapto isobutanol can be used as mercapto alcohol.

[0078] As a surfactant added by the coolant which uses water as a principal component, ARUKI roll amide systems, such as polyhydric-alcohol systems, such as polyoxyethylene systems, such as polyoxyethylene alkyl phenyl ether and polyoxyethylene mono-fatty acid ester, and sorbitan mono-fatty acid ester, or fatty-acid diethanolamide, can be used as an anion system as sulfonic acid types, such as sulfate molds, such as fatty-acid derivatives, such as fatty-acid soap and naphthenic-acid soap, or a long-chain alcoholic sulfate, and sulfated oil of animal and vegetable oils, or a petroleum sulfonate, and a non-ion system. Specifically, surface tension and a dynamic friction coefficient can be adjusted within the limits of predetermined by adding chemical solution type JP-0497N (castrol company make) about 2% of the weight in water.

[0079] Moreover, as synthetic type composition lubricant, a synthetic solution type, a synthetic emulsion type, and a synthetic soluble type can be used, also in it, a synthetic solution type is desirable and the lubricant (#830 and #870 by YUSHIRO CHEMICAL INDUSTRY CO., LTD.) which specifically contains a glycol, alkanolamine, etc., and SHINTAIRO 9954 (castrol company make) can be mentioned. All can adjust surface tension (or dynamic friction coefficient) within suitable limits by adding in water 2 % of the weight to about 10% of the weight.
[0080] Moreover, the corrosion of a rare earth alloy can be prevented by making a rust preventive contain. Here, as for PH, being referred to as 8-11 is desirable. As a rust preventive, a phosphoric acid salt, a borate, molybdate, a tungstate, or a carbonate can be used as amines, such as carboxylate, such as oleate and a benzoate, or triethanolamine, and an inorganic system as an organic system.
[0081] Moreover, nitrides, such as bends triazole, can be used as nonferrous metal anticorrosives, and formaldehyde donators, such as hexa hydro triazine, can be used as antiseptics, for example.
[0082] Moreover, a silicone emulsion can be used as a defoaming agent. By making a defoaming agent contain, foaming of the coolant is lessened, the permeability of the coolant is improved, the cooling effect is heightened, the temperature rise in a wire saw 20 is prevented, and an abnormality rise and anomalous attrition of the temperature of a wire saw 20 stop being able to happen easily.
[0083] The structure of the wire saw 20 suitably used with this operation gestalt is explained referring to drawing 3 . In addition, all over drawing, the lower half is simplified from Chuo Line shown with the alternate long and short dash line of a wire saw 20.
[0084] As a wire saw 20, what fixed the diamond abrasive grain 24 in the resin layer 26 is suitably used for the peripheral face of a core wire (piano wire) 22. Also in it, it is desirable to use phenol resin as resin. The bond strength of phenol resin to the peripheral face of piano wire (hard drawn steel wire) 22 is high, and it excels also in the wettability (permeability) to the coolant mentioned above.
[0085] As an example of the suitable wire saw 20, the diamond abrasive grain whose mean particle diameter is about 45 micrometers is fixed on the periphery of the piano wire 22 whose diameter is about 0.18mm in the phenol resin layer 26, and the wire saw 20 whose outer diameter is about 0.24mm is mentioned to it. Moreover, as for the mean distance between the abrasive grains 26 which adjoin mutually in the transit direction (shaft orientations: direction parallel to the one-point broken line in drawing) of the viewpoint of a cutting efficiency and the discharge effectiveness of cutting waste (sludge) to the wire saw 20, what is within the limits of 200% - 600% of the mean particle diameter D of an abrasive grain is desirable. Furthermore, as for the average height of the

part which the abrasive grain 22 has projected from the front face of the phenol resin layer 26, it is desirable that it is within the limits of 10 micrometers - 40 micrometers. Such a wire saw 20 has eccritic [good] while having a good cutting efficiency, since the space (called a "chip pocket") 28 of moderate magnitude is formed between abrasive grains 22.

[0086] Here, the example of the result of having examined the addition dependency of the extreme pressure additive given to the cutting property of a rare earth alloy about the coolant which contains a sulfuration oleic acid diethanolamine salt as an extreme pressure additive is explained.

[0087] The wire saw equipment 100 shown in drawing 1 was used for cutting. As a wire saw 20, the wire saw by which the industrial diamond abrasive grain with a particle size of 40 micrometers - 60 micrometers was fixed to the core wire with a diameter of 180 micrometers in the phenol resin layer with a thickness of 15 micrometers - 40 micrometers was used. The mean distance between abrasive grains was about 100 micrometers.

[0088] Using NEOMAX-46 by Sumitomo Special Metals Co., Ltd. as a work piece, the die length of a cutting slot was set to 200mm, is in the condition which kept the fall velocity of a work piece constant by 40 mm/h, and measured the tension Fx (the transit direction of a wire saw 20) concerning a wire saw 20, and the reaction force (Fz) over the descent direction using the Xtal piezo-electricity type load cell.

[0089] as cooling water, the YUSHIRO CHEMICAL INDUSTRY CO., LTD. make is synthetic in water (tap water) first -- what did 10 volume % mixing of type composition lubricant #830 was prepared. What added the amount (volume criteria) which shows a sulfuration oleic acid diethanolamine salt in Table 1 was used for this as coolant.

[0090]

[Table 1]

極圧添加剤濃度（ppm）	0	500	1000	2000
切断速度（mm/H）	24.6	29.3	35.7	33.1
切断抵抗：ﾜｲﾔ 1 本あたり				
Fx 張力（N）	0.95	1.13	0.97	0.84
Fz 仕事量（N·m$\times 10^{-3}$）	319.8	351.5	353.0	301.9
切断速度換算				
Fx 張力（N）	1.38	1.38	0.97	0.91
Fz 仕事量（N·m$\times 10^{-3}$）	464.1	428.3	353.0	325.6

[0091] Fx and Fx are falling by adding 500 ppm or more of extreme pressure additives so that clearly from the result of Table 1. Although the fall inclination of this cutting resistance was checked to about 20000 ppm, corrosion was looked at by some work

pieces when it exceeded 20000 ppm. Moreover, the inclination for the fall of cutting resistance to be mostly saturated in 1000 to 5000 ppm was seen. From these things, it can be said that it is desirable that it is 20000 ppm or less as for the addition of the extreme pressure additive to cooling water, and it is still more desirable that it is [1000 ppm or more] 5000 ppm or less.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] In order to perform cutting process of the rare earth alloy of the operation gestalt by this invention, it is the mimetic diagram showing the wire saw equipment 100 used suitably.
[Drawing 2] It is the mimetic diagram showing the configuration near the cutting section of the wire saw equipment 100 shown in drawing 1 .
[Drawing 3] In order to perform cutting process of the rare earth alloy of the operation gestalt by this invention, it is drawing showing typically the cross-section structure of the wire saw 20 used suitably.
[Description of Notations]
10a, 10b, 10c Maine roller
20 Wire Saw
30 Tub
40a, 40b Reel bobbin
42a, 42b Traverser
50 Work Piece
60 Coolant Tank
70 Pan for Recovery

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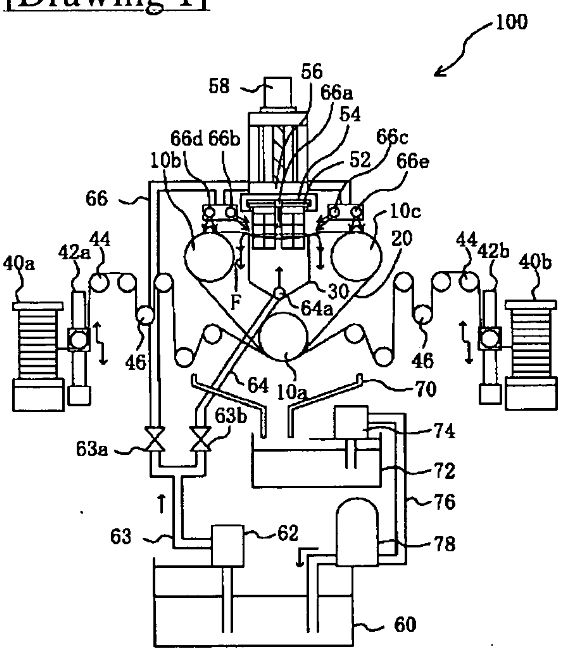
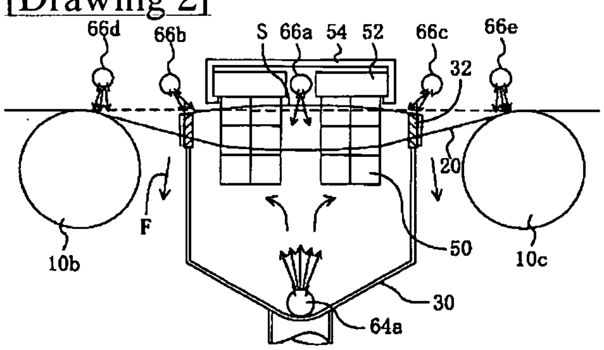
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DRAWINGS

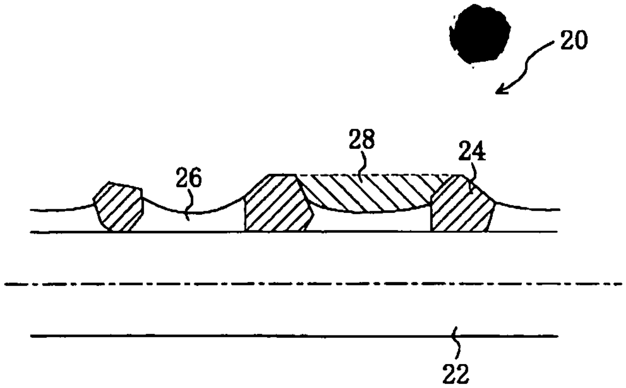
[Drawing 1]



[Drawing 2]



[Drawing 3]



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